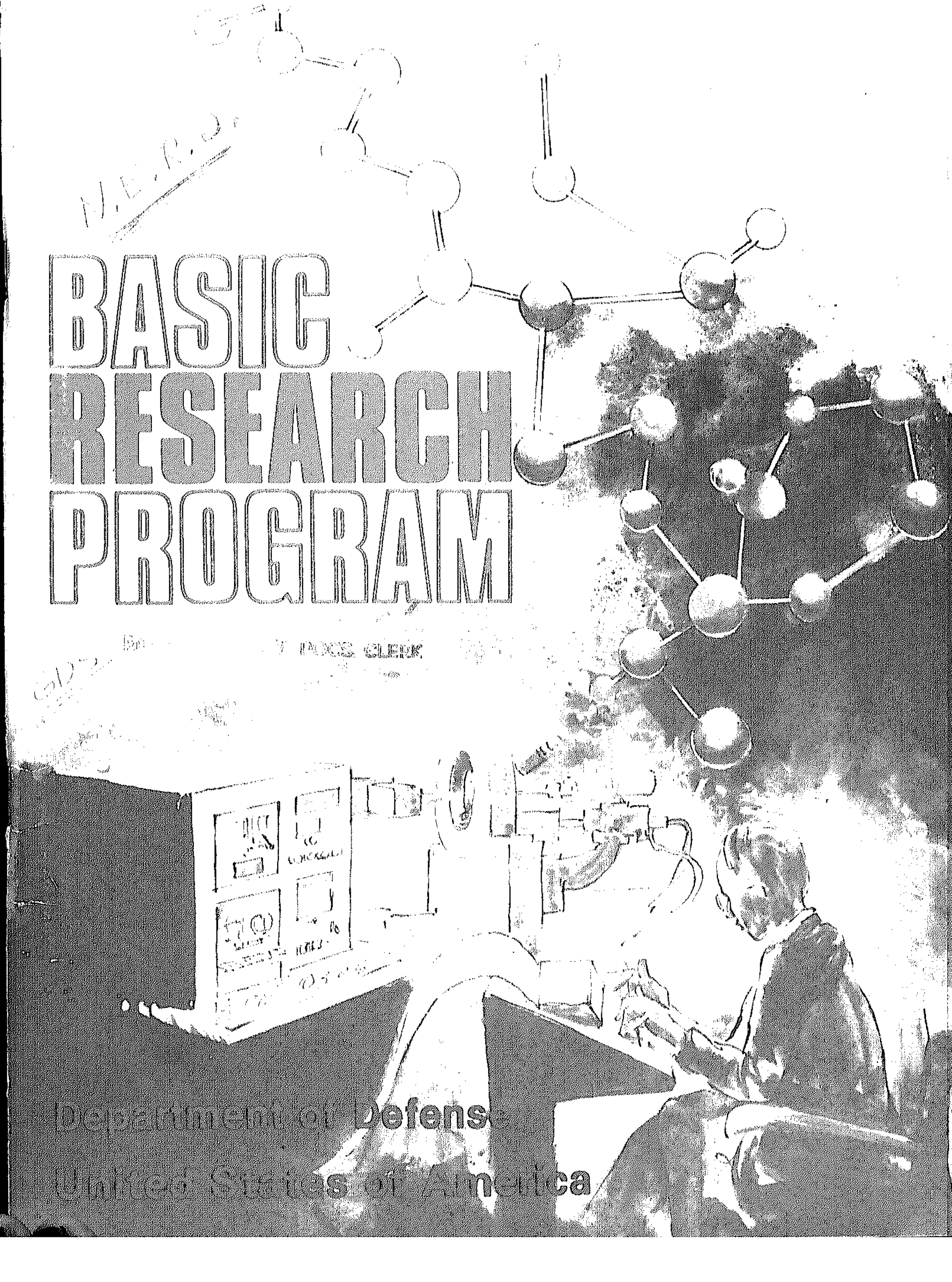

BASIC RESEARCH PROGRAM

Department of Defense

United States of America

FOREWORD

No single investment made by the Federal Government in this century has resulted in a greater return to the U.S. Treasury than Defense-oriented research. This report is part of a continuing effort to improve communication with the national research community by increasing the visibility of the DoD research program. Examples given here of research accomplishments as well as research needs reaffirm the importance of basic research to the Department of Defense.

For Fiscal Year 1986, a new University Research Initiative has been prepared and incorporated into the President's budget to Congress. Details are now being formulated by the Army Research Office, the Office of Naval Research, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency, under the guidance of this Office. This initiative is rooted in our belief in the vital part played by universities in undertaking Defense research, and in our conviction that we must provide the best possible education for our future scientists and engineers.

This document presents an overview of the DoD basic research program by sampling the entire range of scientific disciplines of interest to DoD. Because of space constraints, we can cite only a few specific examples. Many exciting parts of the program cannot be described in detail; however, this should not be taken to indicate lack of interest or low priority.

We acknowledge the assistance generously provided by the Army Research Office, the Office of Naval Research, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency. I wish to express my appreciation to all who contributed so generously of their time and efforts to this report. My special thanks go to Dr. Leonard Caveny of the Air Force Office of Scientific Research for conceiving, organizing, and creating this edition. This document was produced at the Naval Research Laboratory under the careful supervision of Dr. Pat Creech and Mr. Earle Kirkbride.

As this report is going to press, we have just learned that the Nobel Prize for Chemistry was awarded to Dr. Jerome Karle of the Naval Research Laboratory for his research on determining the three-dimensional structure of complex molecules by using X-ray diffraction techniques. Dr. Karle shares the award with Professor Herbert A. Hauptman, a former employee of the Laboratory, now affiliated with the Medical Foundation of Buffalo.

Leo Young

Leo Young
Director, Research and
Laboratory Management
Office of the Deputy Under Secretary
of Defense (Research and Advanced
Technology)

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Introduction

"Science is important to the preservation of our republican government and it is also essential to its protection against foreign power."
Thomas Jefferson, 1821

The present administration is committed to ıce and apply—more successfully than in the -those areas of science and technology ıtial to maintaining our national defense ›ility. The science and technology programs ıe Department of Defense (DoD), aug- ed by the efforts of other federal agencies he private sector, provide the foundation for y effective armed forces equipped with tech- ;ically superior weapon systems.

This technological superiority is accom- :d by a DoD research program that is, on ıand, responsive to the needs of the defense lishment while, on the other hand, strongly d to the traditional strengths of the academic ndustrial sectors.

This document serves several purposes:

- Explains the DoD research program to researchers, both in and out of government;
- Shows how the program fits into the national research effort;
- Describes the program structure both in terms of technology efforts and relevance to the objectives of each military service;
- Summarizes the major areas of emphasis, including selected current research efforts and accomplishments; and
- Solicits involvement from the research community in building a stronger research program.

This document describes both the research :am's technical composition and its management by the DoD. This approach should give the reader a broader understanding of the DoD research program.

What Is 6.1?

The Defense Budget Breakdown

The annual defense budget is divided into 10 categories for accounting purposes. The R&D portion of the budget, or in DoD language, the RDT&E (Research, Development, Test, and Evaluation) budget is the sixth of the 10 budget categories. The activities within this budget category are numbered as follows: 6.1, basic research; 6.2, exploratory development; 6.3, advanced development; 6.4, engineering development; and 6.5, management and support of R&D activities. The remaining R&D programs fall into operational systems development. Table 1 shows current allocations of funds for these categories.

Table 1—RDT&E by Budget Categories

	FUNDING ($M)		
	FY 1984	FY 1985	FY 1986
6.1 Research	843	861	971
6.2 Exploratory Dev	2,212	2,261	2,555
6.3 Advanced Dev	5,936	6,837	11,683
6.4 Engineering Dev	9,165	10,917	10,747
6.5 Mgmt & Support	2,406	2,436	2,744
Operational System Dev	6,375	8,140	10,580
Total	$26,938	31,452	39,280

Technology Base—6.1 and 6.2

The combination of the categories 6.1 and 6.2 is referred to as the Technology Base or the "tech base" part of the program. Efforts within the tech base provide the means through which technical options may be found for midterm and long-term solutions to national security problems. Projects range from basic scientific investigations (basic research) through which new phenomenology is discovered, to demonstrations of promising technologies that may subsequently become building blocks for new operational systems.

Basic Research—6.1

The budget category 6.1, the basic research portion, differs from the other categories because basic research is not necessarily expected to result directly in a military product.

The 6.1 activity supports fundamental investigations into the nature of basic processes and phenomena, selecting projects primarily on the basis of the quality of the approach and their potential relationship to the DoD mission. Primary emphasis is on high quality basic research which results in better understanding of the fundamental processes of nature. This understanding is necessary for the future development of military applications.

Where Does 6.1 Lead?

A 6.1 program successfully completed often leads to more applied efforts; for example, a 6.2 program to explore the use of the concept in a configuration with military relevance. This funding sequence provided for the development of the laser, which was largely supported by DoD from the time of its invention when it seemed a novel idea with long range potential for the Military. Today, the laser is found in almost all aspects of military research, training, and operations, and its use is expanding rapidly. (Other examples of the impact of basic research on the nature of warfare will be discussed later.)

How DoD Views Its 6.1 Program

DoD has supported basic research since the beginning of the Nation's history. The first government-sponsored research program was the Lewis and Clark Expedition funded by the Army in 1804. When Congress established the Office of Naval Research (ONR) in 1945, DoD became the first government organization to formally support basic research. The DoD commitment to fundamental research continued with the establishment of the Army Research Office (ARO) in 1951 and the Air Force Office of Scientific Research (AFOSR) in 1952. Later in the 1950s the Defense Advanced Research Projects Agency (DARPA) was started. However, support for basic research fluctuated through the years. In the late 1960s emphasis shifted toward near-term payoffs, and funding was held more or less unchanged.

In 1970, the Mansfield Amendment required that all basic research funded by DoD must have a "direct and apparent relationship to a military function or operation." The following year, the Amendment was changed to state that there need only be a "potential relationship to a military function or operation," rather than "direct and apparent relationship." While the Mansfield Amendment causes the relevance of basic research to be considered, it does not detract from a long-term fundamental research approach.

By the mid-1970s, DoD recognized that the past approach to research management had cost DoD a 60% loss in purchasing power because of inflation. Further, this approach was risking the loss of valuable assets: DoD's relationship with the scientific community and its ability to tap the innovative ideas of independent scientists and engineers. In 1976, the Secretary of Defense, through the Defense Science Board, recognized that this pattern of supporting basic research was not likely to provide the necessary options for defense needs and sustained technological growth. A program of real funding growth and increased emphasis on high-risk, high-payoff, and long-term research was then initiated.

In 1978, the President's Science Advisor appointed a working group (referred to as the Galt Committee) to review the policies and practices of DoD's basic research program. The committee concluded:

> "The DoD has supported basic research for decades, and it must continue to do so if it is to pursue its overall national defense objectives at the highest possible level of effectiveness, efficiency, and insight. There are three fundamental reasons. Many known technological problems stem from gaps in knowledge which only basic research can fill. Basic research is a source of new concepts which introduce major changes in technological and operational capability. And, finally, it is a source of insight for DoD policymakers and others in evaluating and reacting to the possibilities inherent in technical proposals and in technological developments anywhere in the world....The support of research has in the past benefited the DoD greatly, and will do so in the future, since DoD's capabilities are based squarely on the technological strength of the United States. The use of high technology to preserve and insure our military posture and thereby to stay ahead of our potential adversaries may very well be the key element in our security in the years ahead."

In support of its conclusions, the Galt Committee cited examples of the impact of basic research on the conduct of warfare and noted that its importance is not always recognized:

> "The part played by basic research in the essential and continuous modernization of these military forces has not always been fully recognized. As recently as just prior to World War II, the Department of the Army and the Department of the Navy were doing almost no basic research. The Navy record, as an example, shows $8.9 million for all Research and Development in 1940. The result was a defense force not well informed of technical possibilities, nor fully aware of the engineering and scientific opportunities available to it. Early in World War II, these shortcomings were painfully recognized, and heroic efforts to overcome them were undertaken. These efforts introduced a variety of new technologies. For example, radar, the proximity fuze, nuclear weapons, homing torpedoes, jet aircraft, rockets, and missiles—which changed the conduct of the war, and continue to have impact today on the military strength and readiness of the United States."

As a result of recommendations made by the Galt Committee and others who critically examined the DoD basic research program, numerous changes were made in the program. New investment strategies were established along with commitments to increase funding. Additional efforts were initiated to renew and strengthen DoD relationships with the scientific community, especially with universities. A new management structure, including the new position of Director for Research, now the Director of Research and Laboratory Management, was established. A new and simplified contract format was adopted to make the contracting process more responsive to the special needs of the research community.

Structure of the 6.1 Program

The DoD RDT&E program comprises approximately 50% of the entire Federal R&D budget. Of this budget, approximately 3.1% is devoted to basic research. This is estimated to be about $840 million in FY 1984 and approximately $861 million in FY 1985. In FY 1984, 47% was performed by universities and the remainder was carried out by DoD in-house laboratories, national laboratories, and industry, including nonprofit organizations.

DoD basic research funding to universities was approximately $430 million in FY 1984. This research supports approximately 4,000 graduate students each year. In addition, each service established graduate fellowship or assistantship programs, which in 1984 supported almost 200 students pursuing advanced degrees in disciplines

important to the defense mission. Many of these students also have summer DoD laboratory research experiences, since DoD laboratories employ approximately 800 co-op students a year. To expose university faculty to DoD research needs, DoD sponsors faculty members for summer research opportunities in DoD laboratories. In 1983, more than 300 faculty members, as well as 50 graduate students, participated.

To encourage students to seek careers in science and technology, promising high school students are offered summer research experiences/apprenticeships in DoD laboratories or with university researchers under contract to DoD. Over the past 5 years, more than 2,000 students have participated. In the summer of 1984, DoD tested a new program, modeled after the DoD high school apprenticeship program, to enable high school science and math teachers to have summer research experiences in DoD laboratories to enhance their teaching of science and math.

The efforts of DoD over the past 4 years are substantive in strengthening the scientific and technological research and education. These efforts address the well-founded national concern that deterioration in this area affects our competitive stance in the world, as well as our national security. Clearly, this is a national problem that is being addressed as a coordinated effort involving schools, universities, high technology workplaces, and government.

RDT&E Organization

The RDT&E program is vertically organized. Many of the concepts enter the system at the basic research (6.1) level, where fundamental investigations into the nature of basic physical processes are conducted. Successful completion of a 6.1 program frequently leads to Exploratory Development (6.2) in which the proven concept is used in or applied to some device having potential military application. This is sometimes called the "breadboard stage." The Advanced Development (6.3) stage follows, during which a prototype or "brassboard" of a specific system or subsystem is built and tested as a confirmation of the successful 6.1 and 6.2 research. Finally, Engineering Development (6.4) reconfigures the successful prototype in preparation for production, should circumstances require it.

The obvious foundation for the overall process is the 6.1 program; hence, the renewed emphasis on managing the program for greatest effectiveness. As a step toward this goal, the Defense Committee on Research (DCOR), which has members from the three military services, the Defense Advanced Research Projects Agency (DARPA) and the Strategic Defense Initiative organization, is chaired by the DoD Director of Research and Laboratory Management. DCOR serves as a 6.1 coordinating and policy-making group in the Office of the Under Secretary of Defense for Research and Engineering. The group is concerned with interservice cooperation, the solution of managerial problems, and the consideration of urgent research needs.

Along the same lines, but at the technical working level, interagency working groups operate in diverse research areas. The purpose of such groups is to coordinate the activities in a particular area of science which involve sectors beyond DoD. Such groups strive to eliminate duplication of effort, provide for a greater interchange of information, enable the sharing of facilities, and make more effective use of each agency's funds.

The Research Performers

Those who perform basic research pertinent to the needs of DoD are both scientists and engineers working within the DoD and national laboratories and those working within industries and universities. Thus, the DoD research effort has two distinct parts: the in-house research program conducted within the military service laboratories, and the extramural program funded by contracts and grants with industry and universities.

DoD in-house laboratories, more than 70 in number, are vital and integral forces in the

defense R&D program, which, in turn, provides the technological foundation for our national security. They help lead the search for new knowledge and concepts, along with the design, development, and the procurement of new systems. The in-house laboratories provide analytical advice and technical services in planning DoD's R&D program. These laboratories must maintain high scientific and technical competence so that outside technical advice can be evaluated and put into proper perspective in the decision-making process. They provide the strong base of technical knowledge necessary for effective assistance in acquiring new systems; that is, to help make DoD a "smart buyer." One of the laboratories' more basic responsibilities is the maintenance of a highly competent technical staff to keep DoD and the services informed of the latest scientific and technical opportunities pertinent to defense needs.

Through a program in research, laboratories provide their investigators with opportunities to keep abreast of new discoveries and to engage in meaningful interaction with the rest of the scientific community. The in-house research program serves to increase the technical abilities of the laboratories and to attract new and imaginative scientists and engineers into defense-related basic research.

The DoD extramural research program involves the support of basic research in both industrial and university laboratories. The research offices of the three military services, the Army Research Office (ARO), The Air Force Office of Scientific Research (AFOSR), the Office of Naval Research (ONR), and the Defense Advanced Research Projects Agency (DARPA) support most of the DoD basic research in universities, while the military laboratories support significant efforts within industry. The university program, as expected, tends to pursue research which offers long-term payoff, while that funded in industry is often nearer term and related more closely to the interests and needs of the sponsoring military laboratory.

As indicated earlier, universities are a major extramural performer of DoD 6.1 research, conducting about one-half of the effort. This is not surprising since universities produce virtually all new members of the scientific community, and these are institutions in which basic research is a major function inextricably interwoven with advanced education.

Most of DoD's extramural research programs are supported through individual contracts and grants. However, a particularly innovative portion of this support is the establishment of multidisciplinary programs focused on complex DoD problem areas. These programs, which provide 3 years or more of stable support, are carried out by groups of researchers at universities. Each group is managed by a senior scientist, who accepts the additional responsibilities of providing clear direction and coordination. Examples of such programs are the Tri-Service Joint Services Electronics Program (JSEP) and the Joint Services Optics Program (JSOP), in which ARO and AFOSR participate cooperatively in supporting major projects. Although JSEP is not new, the multidisciplinary concept of research management is now being emphasized more strongly. Most multidisciplinary programs are funded by a single service, with other services and agencies participating in reviews.

The Management

The role of DoD management in the research program is to provide fertile ground for the development of new research opportunities. Such opportunities come through unsolicited proposals, scientific liaison with other departments and agencies, professional society participation (meetings, journals, personal contacts), scientific advisory panels, top-down requirements, research innovations and breakthroughs, and the evaluation of foreign intelligence. Once a research opportunity is recognized, management then strives to exploit it. Signature suppression, less vulnerable communications, space propulsion, improved visibility in degraded environments, elimination of corrosion, advanced energy beaming weapons, artificial intelligence, robotics, and microelectronics are examples of current research opportunities.

Measuring the success of this approach is not straightforward. One could count the number of published journal articles resulting from DoD-sponsored research, or the number of literature citations received, or the number of patent applications, or use of any of a dozen other metrics, and then draw conclusions based on these statistics. One such metric might be the nearly 20 Americans who have received Nobel prizes this past decade while working on DoD-supported programs. Even more important than these success measurements, however, is the feeling of productivity and goodwill engendered between the research community and the DoD research establishment. DoD continually strives to preserve and enhance the mutual benefits to each group.

Because of the importance of the role of university basic research to the goals of DoD, several steps are under way to improve the relationship between DoD and the university scientific community. This relationship deteriorated during the late 1960s and the early 1970s because of an unpopular war and decreased emphasis on the support of basic research by DoD. Also, in 1970, the so-called Mansfield Amendment to the Military Authorization Act placed restrictions on the type of research appropriate for DoD support. Although the wording of the Amendment was changed the following year to recognize the need for DoD to support fundamental research, some residual effects of the Amendment continued for several years and in effect caused the DoD effort to tend toward short-term research performed by universities. This trend was reversed, however, and the DoD and the academic sector have now restored their productive partnership in the mutual pursuit of long-range, fundamental ventures in scientific inquiry.

Periodically, special programs are used to achieve specific DoD goals. The University Research Instrumentation Program (URIP) is a 5-year, $150 million DoD initiative to improve the capability of universities to perform research in support of national defense. This program provides funding for large items of equipment ($50,000 to $500,000 range). The solicitation for the final 2 years of the program became available from the Army Research Office in the summer of 1985. The Small Business Innovation Research Program (DoD-SBIR) was implemented to stimulate and to support small business in conducting high quality innovative research and development connected to important defense-related scientific and engineering problems and opportunities. In July 1982, by Public Law 97-219, Congress mandated that prescribed percentages of the extramural tech base budget be set aside for this program. The DoD-SBIR program provides for a three-phase approach. Phase 1 awards are intended to permit the determination of the scientific or technical merit of a proposed research and development effort. Phase 2 awards are made to firms based on the success of Phase 1 and the potential of the proposed effort to satisfy a particular military need. Under Phase 3, the expectation is that non-Federal capital will be used to pursue commercial applications, or that Federal non-SBIR funds will be used for DoD mission-oriented contracts for products and processes.

Accomplishments

Before proceeding to a description of some of the current research directions, it is appropriate to note some of the accomplishments generated from the DoD basic research program. Efforts during World War II had a tremendous impact on the nature of warfare. Research during the 1950s and 1960s led to the maser and laser, integrated circuits, intercontinental missiles, computerized weaponry, vastly improved communications systems, and advances in medical science.

The following are just a few examples of significant accomplishments made during the past 2 years:

- Research on computer-generated images has resulted in algorithms which yield more realistic displays under conditions where the sensing rays are scattered by the object, such as in IR, laser, and radar illumination. These algorithms are aiding in the determi-

nation of signatures, "hot spots," and battlefield targets.

- A technique for analyzing distributed gain devices as millimeter wave sources has been established. Transient time of charged carriers within conventional solid state sources limits the frequency of operation. In this advancement, gain is accumulated as the wave propagates along its axis in synchronism with the charged carriers. In this manner, transit time is used to advantage and no longer represents the critical frequency limiting parameter.
- Halide glass research has pioneered the development of chemically stable glasses that transmit light in the infrared region without scattering or attenuating the light. These glasses are improving fiber optic communications and infrared domes, lenses, and mirrors.
- A modified betatron that is compact and able to accelerate currents a thousand times more than in conventional betatrons has been demonstrated. These accelerators are promising drivers for new compact radiation sources for radar, countermeasures, and directed energy weapons.
- A deep-towed (e.g., for 100 meters above the bottom at depths of 6000 meters) geophysical system has been developed and tested which provides significantly better definition of ocean bottom properties.
- Combustion research on metallic fuels provided for new solid propellant formulations for upper stage rocket engines. The resulting propulsion systems overcome the performance limitations of metal slag accumulation and result in significant increases in orbital payloads.

The research program in FY 1985 will continue to cover a broad range of science and engineering topics of critical importance to the defense mission. The funding increases in FY 1985 and FY 1986 will be used to strengthen areas or overcome serious inadequacies in the current level of effort.

The budget for the DoD 6.1 research program is made up of two segments. The major portion of the program (92%) is in the program elements called Defense Research Sciences (DRS). The DRS programs include all the extramural efforts and most of the 6.1 tasks performed in the in-house laboratories. The objectives of the DRS program are to (1) ensure that the scientific and technological base related to national defense is the best in the world, (2) provide a broad and balanced foundation of fundamental information in scientific areas of interest to DoD, (3) identify today's scientific opportunities which address tomorrow's defense requirements, (4) counter the Soviet threat to our technological superiority, and (5) prevent or create technological surprise.

The remaining 8% of the 6.1 program is allocated to the In-House Laboratory Independent Research (ILIR) program. This unique program provides individual laboratory directors with discretionary funds for what might be called "venture capital" to enable them to take immediate advantage of technological opportunities and to maintain a research base in the DoD laboratories. ILIR funds are restricted to the DoD laboratory director's use, but can be contracted out by the laboratory. They may not be used merely to shore up regularly funded programs that have overrun their budgets, but are used to concentrate on timely new approaches to problems that might not ordinarily be supported since they fall outside the normal funding cycle. The technical directors report on their ILIR programs directly to their Service Assistant Secretary for R&D with no review by any intervening layers of management. The programs are reviewed after the fact, with each year's funding dependent upon the results of the previous year's efforts.

Summary

To summarize, DoD views its 6.1 program as the source of its future technology. The Director of Research and Laboratory Management, in the Office of the Under Secretary of Defense for Research and Engineering, and the 6.1 program managers in the DoD agencies are responsible for improving the technology transfer process. Accomplishments in the 6.1 program must be

quickly passed on to both the research community and the applications program managers. Because of the vertical R&D structure and the fact that many of the in-house organizations doing 6.1 research are also engaged in 6.2 and 6.3 work, the time involved in applying the appropriate results of the 6.1 program can be shortened.

What are the responsibilities of the individual researcher? DoD expects participants in its 6.1 programs to propose and perform the highest quality, most innovative, most creative research possible. Extramural researchers in particular are not expected to justify their proposals in terms of possible end-item applications, although such suggestions are welcomed. In-house researchers, by virtue of their close association to specific military requirements, are charged with responsibility to focus their applications. However, the technical directors of the military service organizations have the ultimate responsibility to affect and facilitate the technology transfer (under the guidance and review of the Director of Research and Laboratory Management) and thus to preserve the more fundamental nature of 6.1 programs (compared to the more applied 6.2 programs).

The quality of science is the most important criterion for the acceptance and funding of proposals, followed by the potential relationship of the proposal to the DoD mission. The weight given each of the criteria in the decision-making process varies somewhat from case to case, depending on the availability and source of funds and the extent of support by other federal agencies. As might be expected, the focusing of fundamental research on mission areas increases from the extramural program (as administered by ARO, ONR, and AFOSR), to contracts from DARPA and the defense laboratories, to work performed in-house.

An important part of the basic research is to recognize the potential of important new topics and radically different approaches. New research opportunities and initiatives come from the research community in the form of unsolicited proposals. DoD is willing to provide the management, coordination, and funds necessary to turn new, high-risk, high-payoff concepts into reality.

How DoD Basic Research Affects the Nation

Practical Applications

From the time of World War II, the DoD research program has strongly affected our Nation in nonmilitary areas; the development of radar and synthetic rubber are two prominent examples. From a desire to improve the GI's canned C-rations came new methods for freezing, drying, and preserving food; the printed circuit board found in every inexpensive portable radio evolved from the effort to make proximity fuzes for artillery rounds more gun-rugged; and, of course, there is the ubiquitous laser, with its applications still expanding. Treatments for tropical diseases, cryogenic preservation of blood plasma, improved construction techniques, resuscitators and heart pumps, goggles to aid victims of *retinitis pigmentosa,* and even fluidic lawn sprinklers, have grown out of DoD basic research programs.

Informally, the DoD R&D program weaves itself into the fabric of national life in a pervasive though not always obvious way. The very-high-speed integrated circuit (VHSIC) program now in progress will have a major effect on the electronics industry; VHSIC will eventually enter our lives in ways that will make the wonders of children's talking toys and personal computers seem elementary by comparison. Similarly, work on parallel arrays may profoundly affect the next generation of large computers.

Technology Transfer Program

The DoD 6.1 research program responds primarily to the military needs of the Nation; however, through both formal and informal contracts, the research program has influence beyond its defense-related obligations. The Domestic Technology Transfer program was formally established to allow the expertise and accomplishments of DoD laboratories to be made available to civilian governmental organizations at the local, state, and federal level. This program originated in 1971, when 11 DoD laboratories joined

together to form the DoD Technology Transfer Consortium in an effort to improve domestic technology transfer processes. The Deputy Secretary of Defense endorsed the program in 1972, subject to various conditions. (For example, the work must be compatible with existing DoD capabilities and facilities, and it must not impede the accomplishment of a laboratory's mission work). The Consortium has grown to more than 200 laboratories and centers representing 11 federal agencies. The DoD has been an active participant in the domestic technology transfer process, and under the Under Secretary of Defense for Research and Engineering has formally reaffirmed its commitment to the program every 2 years. Most recently, the process of technology transfer has been formalized and reinforced by DoD and other federal agencies through mechanisms provided by the Stevenson-Wydler Technology Innovation Act of 1979 (PL96-480).

NRC Study

The National Research Council study "Science and Technology: a Five-Year Outlook," performed for the Office of Science and Technology policy, discusses the current state of several aspects of our national technology base and highlights trends and areas for future emphasis. This study mentions many areas in which DoD is participating: earthquake hazards, ocean dynamics, synaptic transmission in nerve cells, amorphous solids, surface phenomena, graphite intercalated compounds, organic conductors, molecular beam epitaxy, robotics, superconductors, electronics displays, composite materials, powder metallurgy, computer-aided design/manufacture, and others.

Such programs are not planned as part of an overall national program. They "happen" for several reasons: the military shares many similar problems with the civilian sector; the military researcher is well-connected to the civilian scientific community through journals, symposia, and the like; and a great deal of the DoD research program (over half in FY 1985) is performed by contractors and grantees in the private sector.

This Report

To the outside community, DoD may be intimidating, a large organization difficult for researchers to penetrate to find out "who is interested in my idea." To help the researcher find possible sponsors easily, the body of this report is divided into two parts: scientific disciplines in the first, and organizations of the funding agencies in the second. Table 2 is a matrix showing the 12 classical disciplines delineated by the Office of Research and Laboratory Management and the corresponding divisions within the military service research offices. This is often very important to the outside community, since many of our programs are multidisciplinary and may overlap; for example, solid state physics falls within the categories of physics and electronics in ARO, the category of electronics at ONR and AFOSR, and the category of materials at DARPA.

Rather than providing great detail, the report highlights the individual areas with examples of ongoing programs and a few major accomplishments in each. Some of the requirements for the future are provided as an indication of the directions the program will assume in the years to come.

Appendix A presents a collection of statistical tables that indicates the breadth and depth of the program. Appendix B lists points of contact to assist those wishing to gain access to the DoD research community.

A final word on relevance: all too often good ideas are never brought to DoD's attention because the researcher does not see an immediate "military application." This is unfortunate, since the extramural researcher is usually not the person who should make this determination. DoD managers are interested in all good ideas, and it is the responsibility of scientific program managers, not researchers, to decide on the applicability of a particular research project.

Table 2—Cross Reference of Military Service Research Programs and DoD Disciplines[a]

DoD Discipline	Names of programs within military service research offices		
	Army[b]	Navy	Air Force
Physics, Radiation Sciences Astronomy, Astrophysics	Physics—not including astronomy or astrophysics[c]	General Physics, Radiation Sciences Astronomy & Astrophysics	Physics, Astronomy & Astrophysics
Electronics	Electronics[c]	Electronics	Electronics
Chemistry	Chemistry[c]	Chemistry	Chemistry
Mathematics and Computer Sciences	Mathematics, Electronics[c]	Mathematical Sciences	Mathematics
Mechanics and Energy Conversion	Engineering Sciences	Mechanics, Energy Conversion	Mechanics, Energy Conversion
Materials	Metallurgy & Materials,[c] Chemistry	Materials	Materials
Aeronautical Sciences	Engineering Sciences[c]	Mechanics	[d]
Oceanography	—	Oceanography	—
Terrestrial Sciences	Geosciences[e]	Terrestrial Sciences	Terrestrial Sciences
Atmospheric Sciences	Geosciences[c]	Atmospheric Sciences	Atmospheric Sciences
Biological and Medical Sciences[f]	Biology[g]	Biological and Medical Sciences	Biological and Medical Sciences
Behavioral Sciences	Biology[h]	Behavioral Sciences	Human Resources

[a]The DARPA program is outlined in the section entitled "DoD Departments/Agency."

[b]The Army program division is from the Army Research Office (ARO) and pertains mainly to the extramural program. The technologies listed also pertain to the Divisions at ARO which monitor the work. Because of the large Army in-house laboratory program, the major Commands conducting research in the various disciplines are given in the footnotes. For a fuller explanation of the organization of the Army's 6.1 program, see the section entitled "DoD Departments/Agency."

[c]Programs in the area are also found within Department of the Army Materials Development and Readiness Command (DARCOM) laboratories.

[d]The Air Force does not identify Aeronautical Sciences separately since much of its research in the other disciplines concerns this area.

[e]Programs in this area are also found within the Corps of Engineers laboratories.

[f]There is also a small research program in this discipline being carried out at the Uniformed Services University of the Health Sciences (USUHS).

[g]Programs in this area are also found within the Surgeon General laboratories.

[h]Programs in this area are also found within the Army Research Institute for the Behavioral and Social Sciences.

Scientific Disciplines

Physical Sciences

- **Physics, Radiation Science, Astronomy, and Astrophysics**
- **Electronics**
- **Chemistry**
- **Mathematical Sciences**
- **Computer Sciences**

Physics, Radiation Science, Astronomy, and Astrophysics

Fundamental research in the physical sciences is the largest and most diverse area in the DoD research program. The research is conducted into the properties and behavior of matter at the most basic level. As demonstrated in the past, significant changes in the concepts of physics are likely to lead to important advances in military technology and tactics. The demonstration of the maser in 1953 and the low-power laser in 1960 marked the beginning of a revolution in military tactics that rivals the impact of radar in World War II. The electronic dependence of current military systems is a direct consequence of the application of basic principles of solid-state physics to electronic circuitry. The use of the high-power lasers in weapon systems may well be the most significant influence on military firepower since the origin of explosives. The physical sciences are basic to the entire range of military technology; some examples are the phenomena of photoemission (for night vision), molecular kinetics (in combustion and explosives), and solid-state effects (upon which electronic devices depend).

Atomic and Molecular Physics

Atomic and molecular physics provide significant opportunities for military applications based on detailed knowledge of atomic and molecular structure, the interactions of individual atoms and molecules with electrons and other species, and interactions with electromagnetic fields. These interactions are basic to understanding the transmission properties of electromagnetic radiation in the natural and disturbed atmosphere, and to developing new laser candidates for high- and low-power applications. This research area is also applicable to the development of accurate navigational aids, infrared emitters and detectors, and energy systems.

Topics covered in this area include energy and charge transfer, electronic excitation and relaxation of excited states, state-to-state molecular dynamics, spectroscopic investigations and techniques, fluoresences, radiationless transitions, and optical pumping. The control of atoms and ions using laser radiation and static electric and magnetic fields is of particular interest. Electromagnetic traps and cooling techniques have been developed which can trap from one to 10^4 ions for virtually an infinite length of time and can cool these ions to a fraction of a degree Kelvin. The stopping of atoms in a beam by a counter-propagating laser has been demonstrated. These studies will lead to more accurate and precise atomic clocks which may also be simpler than

current systems. In recent years, the techniques of many-body physics have been used within atomic and molecular physics for a wide range of applications, such as determining the velocity dependence of vibrational excitation of molecules formed in rocket exhausts and computing the activation energies for complex explosives.

Optics and Lasers

The military services have been actively sponsoring research in optics and lasers, since the potential for range determination, weapons guidance, and communications was recognized immediately with the demonstration of maser and laser phenomena. Specific applications will continue to develop as research problems are resolved. These applications include the development of

- lasers in heretofore inaccessible regions of the spectrum, such as the far infrared, ultraviolet, and X-ray regions;
- widely tunable lasers; and
- new approaches to high-power and high-efficiency laser action.

Recently, a new technique for compressing the pulses from a laser to produce shorter duration optical pulses has been achieved. This technique can be used over a continuous range of wavelengths extending from the visible through the near infrared spectrum and does not require high optical powers. The technique (Fig. 1) consists of first passing the pulse through an optical fiber which produces a pulse with a frequency that is continuously changing in a very controlled way from the beginning to the end of the pulse. Because of the controlled manner in which the pulse has been lengthened and its frequencies changed, significant compression is obtained by passing the pulse through a dispersive delay line. The frequencies of the first part of the pulse require that portion of the pulse to travel a greater distance than subsequent parts of the pulse, thereby compressing the pulse. This technique has been used to compress an 8 picosecond pulse to 120 femtoseconds using two stages of pulse compression. This work significantly impacts the study of ultrafast relaxation processes, as well as producing ultrashort duration X-ray pulses for a wide range of applications.

The rapid development of laser techniques has also presented many research opportunities not directly concerning laser devices. For example, nonlinear optical techniques, such as up-conversion and conjugate-wave processing, suggest new ways of handling information.

Optical components such as glass and windows for lasers are also being studied. The effects

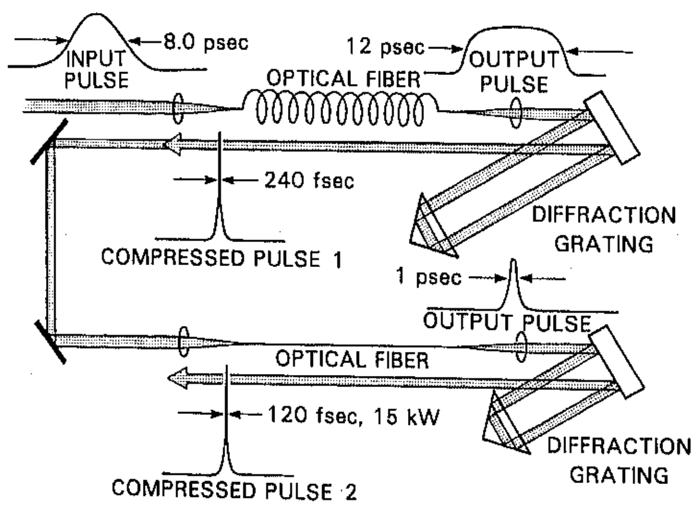


Fig. 1 — Pulse compression schematic diagram, showing fiber optics and gratings employed to achieve femtosecond optical pulses

of electric and magnetic fields on optical materials are of interest, as well. The unique laser properties of monochromaticity, coherence, high intensity, and short pulse lengths are being applied to the study of various material systems and to the production of plasma radiation that is well-suited for use in lithography, chemical analysis, and strain measurement.

Electrical Phenomena in Gases and Plasmas

The study of electrical phenomena in gases and plasmas includes the physics of electrical discharges and electromagnetic interactions with these discharges. The high-priority programs dealing with directed energy fall partially in this area (particle beams supported by DARPA) and partially in the laser area.

The particle-beam program, the newer of the two, has many problems requiring research. The program's needs have been divided into five areas:

- Pulse power—improved repetition rate, improved voltage and current capabilities for switches, materials having increased energy storage density at reduced size, weight, and cost, and prime power sources having increased power density and fuel efficiencies.
- Sources—diagnostics, scalability, improved repetition rate, increased monoenergetic character, and improved beam formation and extraction techniques for high-intensity ion/electron sources.
- Accelerators—improved focusing elements, greater understanding of dielectric breakdown, transport codes for multistaged systems, diagnostics, and high-flux swing magnet.
- Propagation—recombination rates and cross sections for atoms, molecules, and hydrated complexes, effects of ion-equilibrium vibrational populations on hydrodynamics, effects of "dirty air," and improved models of hose and two-stream instabilities.
- Beam-material interaction—low and high flux signatures, thermomechanical damage estimates, collective effects, multipulse effects, and effects on layered targets.

A further example of work supported by DoD plasma physics is research on collective plasma processes, in ionized media and in electron beams, that lead to the production of intense radiation at microwave and millimeter wave frequencies.

Condensed Matter

The military interest in condensed-matter physics is far-reaching and includes such diverse applications as

- initiation and propagation of explosions
- surface phenomena related to corrosion and wear,
- electronic devices for communication and detection, and
- determination of the mechanical and thermal properties of metals and alloys under normal and unusual environmental conditions.

The three military services continue to maintain strong commitments to the support of basic research in condensed-matter systems with many applications to both the military and civilian sectors.

DoD-supported condensed-matter research is making progress in obtaining fundamental understandings of the behavior of solid-state systems, including the capability of predicting new materials with enhanced desirable properties. First-principles equation-of-state methods have been achieved to study phase transitions in ionic solids. An example is the compound $RbCaF_3$ which is known to transform from the cubic perovskite structure to a lower symmetry phase as the temperature is lowered below 195 K, while its isostructural counterpart, $CsCaF_3$, does not transform. Experiment had indicated that the transformation in $RbCaF_3$ is driven by a coordinated displacement of the F^- ions, indicated by the arrows in Fig. 2. Investigators have shown that the origin of the instability is the presence of

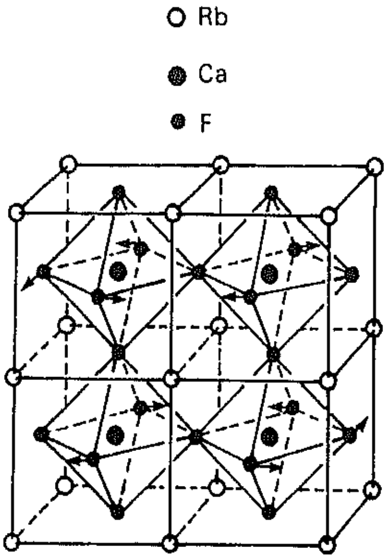


Fig. 2 — Four unit cells of the perovskite structure with arrows at the corners of the CaF_6 octahedra indicating the distortion produced by the transition to the lower-temperature phase of $RbCaF_3$

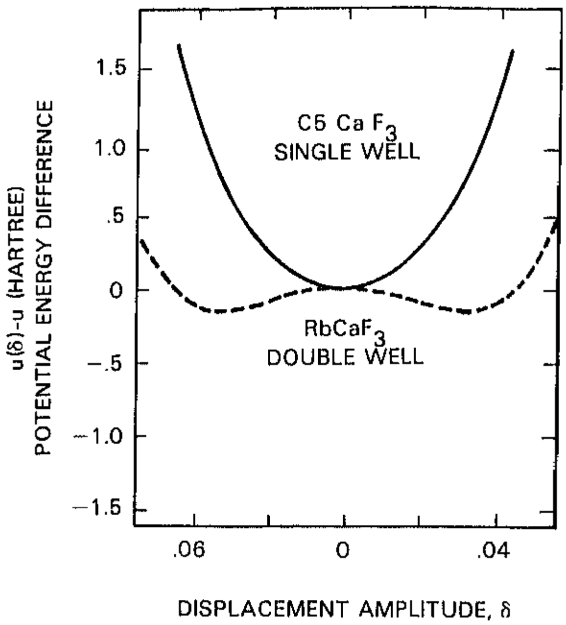


Fig. 3 — Potential energy difference as a function of the displacement amplitude for $CsCaF_3$ and $RbCaF_3$. The double well for the $RbCaF_3$ drives the displacement phase transition, while the lack of transition in $CsCaF_3$ is related to the larger size of the Cs^+ion compared to the Rb^+ion.

a double well in the total energy function U as a function of the F^- displacement amplitude as illustrated in Fig. 3. The lack of a transition in $CsCaF_3$ is related to the larger size of the Cs^+ ion compared to the Rb^+ ion which tends to stabilize the former compound. Studies such as these are being applied to ferroelectric and IR materials of great technological importance.

Radiation Sciences

DoD's need to have reliable space resources in both natural and weapon-enhanced radiation environments sustains research in radiation science. For example, single ions that are present in the paths of orbiting satellites can deposit enough energy in some state-of-the-art integrated circuits to corrupt the stored information. To study this problem, the basic physics of the processes that result in these upsets are being addressed. Test structures typical of integrated circuits are used in conjunction with energetic ion beams from accelerators to measure how energetic ions deposit energy. If enough energy in the form of electronic charge is collected at a sensitive circuit element, upset can occur. For

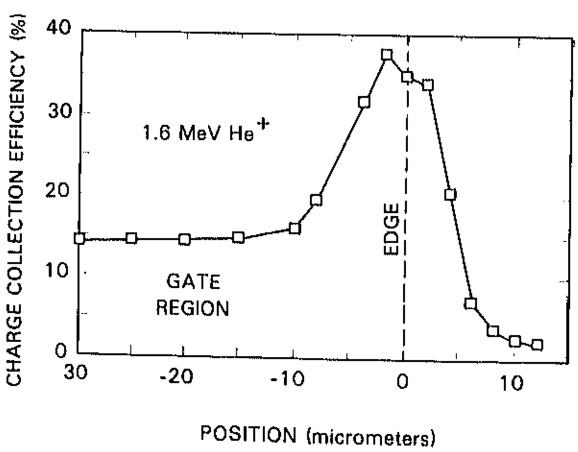


Fig. 4 — Increase in the charge collection efficiency for a gallium arsenide field effect transistor, achieved by influencing the location of an ion beam relative to the edge of the transistor gate. This work is applicable in developing survivable space systems.

example, Fig. 4 shows the percentage of an ion's energy which collects as a function of the position of the ion beam relative to the edge of the gate of a gallium arsenide field effect transistor (FET).

The very surprising result, which may have a large impact on the design of future integrated circuits using this technology, is that when the ions strike the edge of the FET gate at a position of about 15μm from the gate, more energy is collected by the gate than when the ions strike the central region of the gate. Further research in this area can point up solutions to this problem and also shed further light on the process of single event upset.

Acoustics

Much of the DoD support for electroacoustics within the last several years has been undertaken by the Navy, in relation to physical and underwater acoustics for improved sonar and surveillance, underwater communications, signal-processing techniques, reduction of target strength, and investigations of the effects of ocean topography and variability on sound propagation and scattering.

The three military services are interested in acoustic research because of its application to diagnostics; for example, in nondestructive evaluation (NDE). Acoustic techniques are often employed as a probe; an example is the use of photoacoustic spectroscopy to understand radiationless transitions in doped electro-optic crystals. The Air Force has sponsored a major program in NDE and surface acoustics waves for signal-processing devices.

Primary research areas of current interest include nonlinear acoustics, basic studies in acoustics emission, interaction of sound with elastic objects, and physical models for acousto-optic transduction. Interest will continue in extending ocean propagation and scattering models of related at-sea work; physical, chemical and scattering properties of media; and new device principles.

Astronomy and Astrophysics

Because of such critical defense-related missions as surveillance, communications, time and position determination, and missile guidance, the physics of the upper atmosphere and of diverse astronomical and astrophysical phenomena is an area of significant emphasis. The radiation environment at very high altitudes is being studied both from the standpoint of equipment survivability and background effects on surveillance and communication systems. With the increasing interest in space missions during the 1980s, this area of research can be expected to increase in emphasis.

Research in this area includes the observation and interpretation of radio, infrared, optical, ultraviolet, X-ray, gamma ray, and particle emissions from earth, aircraft, balloon, rocket, and satellite platforms. As is typical for scientific investigations in this area, techniques and the development of instrumentation are emphasized.

A major accomplishment in the astronomy area is the catalog of radio stars with positions that have been accurately determined by means of radio interferometers. This work has been carried out by the Naval Observatory and could result in a new standard of reference for navigational and time standards that is much more precise than the existing one based on visible stars. This study revealed important scientific data on the nature of the radio stars.

Another accomplishment in astronomy is the mapping of the background (nonzodiacal) starlight in both red and blue wavelengths over the entire sky under an AFOSR space research contract. Taking advantage of merged Pioneer 10/11 skymaps and the negligible zodiacal light beyond a distance of 2.8 AU, the zodiacal light was isolated and the maps of two colors were established.

Cross-Disciplinary Physics

Many of the greatest opportunities for military applications of science and technology arise from research in the boundary areas between physics and other scientific disciplines and technology. Physics research is a powerful stimulator of fresh ideas for technology. Technology

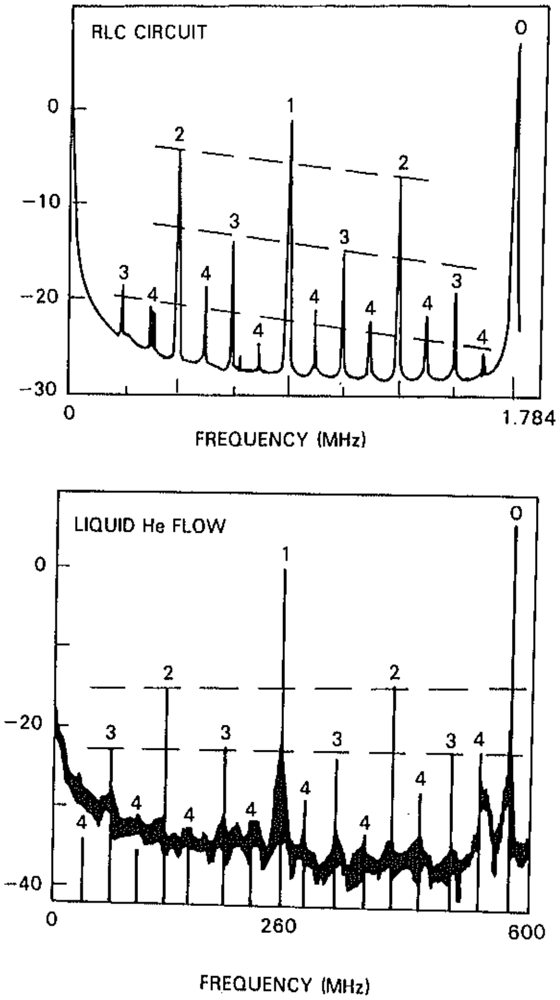


Fig. 5 — Frequency spectra of excitations in two nonlinear systems. In both cases, subharmonics due to period doubling appear in the spectra, suggesting that the precursor to chaotic behavior is not a random process.

responds by providing ways to implement new physics investigations. This mutual dependence of the growth of physics and technology is exemplified by the demonstration of the laser, its subsequent technological development, and the impact that advanced laser technology has made in many spectroscopic research areas.

A major area of current interest concerns nonlinear dynamics and the study of chaos. Many deterministic systems exhibit both smooth (e.g., laminar-flow) and apparently noisy (e.g., turbulent) behavior. It is now understood that the chaos in such systems is not true randomness, but is the result of extreme sensitivity to initial conditions in nonlinear systems. Such behavior is exhibited by electronic, optical, chemical, computer and diverse other systems, in addition to fluids. Research now is aimed at understanding and controlling the transitions between smooth and chaotic behavior. Period doubling is one route by which a quiescent system can become chaotic. Figure 5 includes remarkably similar spectra from nonlinear fluid and electrical systems which exhibit period doubling. Extensive experimental and theoretical work is now in progress in several fields to enumerate and characterize paths to chaos.

Electronics

DoD requires electronic systems having characteristics for high-speed information processing, high reliability and availability, operation in hostile environments, resistance to jamming and interception, exploration of the total electromagnetic spectrum, coordination of interdependent functions, complex and unpredictable situation management, and ease of personnel training and maintenance. The military services have common needs in electronics research: microwave, millimeter, and electro-optical components and materials, high-speed information devices and materials, and an understanding of processes affecting device, circuit, and system reliability. Thus, the research program in electronics has been structured in a logical progression of topics beginning with the study of electronic materials, through the way these materials behave in devices, to the design and construction of components, the combining of components into circuits, and finally, the building of systems based on these circuits.

Physical Electronics

Investigations in physical electronics are directed at the electronic and structural properties of binary, ternary, and quaternary semiconductors, semiconductor surface and interface effects, high field and nonequilibrium transport phenomena, transport physics in ultrasmall dimensions, magnetic effects at high frequencies, and interfaces in optically integrated circuits. Specific research topics include the understanding of such phenomena as the generation, transport, and control of charge carriers in semiconductors, and magnetic and optical properties of materials.

Ultrasmall electronics research (USER) is pushing the frontier of electronics toward a generation of devices with critical dimensions no larger than a molecule. Such small dimensions allow an increase in density of transistors on a single semiconductor substrate and provide substantial increase in data processing speed. As critical dimensions of solid state devices are reduced, time and space domains become small and electric fields large so that new concepts and theories of operations need be developed. For instance, devices with a size approaching the long range order of the material phenomena such as chemisorption, segregation/agglomeration, microinclusions, normally negligible in larger devices, will be of critical importance in this submicrometer range. Current transport theory based on the Boltzmann transport equation will be invalid. Interactions between neighboring structures must be considered. Structural renormalization, synergetic self-organization, collective or coherent operations, and dissipative relaxations, have only begun to be examined. The USER program, initiated during FY 1981, is one of the most exciting research efforts in the DoD program.

A strong program in the study of surfaces and interfaces will continue to address issues on the fundamental nature of Schottky barriers, ohmic contacts, and heterojunction barrier formation. Compound semiconductors will be emphasized, as well as research on ad-atom chemistry, kinetics of atoms on surfaces, and Schottky barrier formation.

Understanding the limitations of the operating ranges of electronic devices is of fundamental importance. The extension of limiting parameters (such as frequency response, speed, power sensitivity, dynamic range, and the like) is of immediate interest. Some exceptionally critical programs fall within this area, such as the entire field of millimeter wave devices (30 to 300 GHz, both sources and detectors). A lack of understanding exists, especially in the atmospheric transmission windows at 94, 140, and 230 GHz. A major thrust is to improve the science base and techniques for the design, fabrication, testing and simulation of integrated circuits, optical circuits, and millimeter wave networks. Special emphasis

is given to gallium arsenide integrated circuits. A new area of research interests has evolved centered around ultrafast optoelectronic processes in thin film semiconductor structures. The recent developments of ultrashort optical pulses combined with new concepts for electronic switching provide opportunities for exploring very fast signal processing.

Antennas, Propagation, and Electromagnetic Detection

The transmission and reception of electromagnetic radiation are essential for military missions. Navigation, radar, electronic warfare, communication direction finding, and electronic countermeasures depend on the full understanding and efficient use of antennas, atmospheric and ground propagation, and sensitive improved detection schemes. Examples of current emphasis are electrically small and conformal antennas, effects of proximity to complex structures, radar imaging enhancement, research in the millimeter region dealing with low cost, high performance antennas, and an improved data base in target/background characterization. Also, solar physics and the effect of space radiation on the reliability of communication links are highly important.

Over the last 5 years, the military services have been supporting research in conformal antenna technology. Because these antennas are physically thin, they can be flush mounted (see Fig. 6) to aerodynamic surfaces of missiles, rockets, remotely piloted vehicles, and projectiles without degrading electrical or aerodynamic performance. Because they are monolithic and fabricated by simple photolithography, they are inexpensive. The investment in conformal antenna research is now beginning to pay dividends.

Radar research has led to new techniques that are important to military and civilian applications alike. The utility of polarization information for noncooperative target recognition is being investigated and significant progress has been achieved in extending optimal polarization theory to the bistatic case. Efforts to extend the geometrical theory of diffraction to nonconducting bodies is being pursued and the important canonical problem of 2-dimensional scatterings from a dielectric half plane has been solved exactly.

Signal Processing, Communications, and Related Systems

Research is concentrating on improving systems performance and reducing the size, weight,

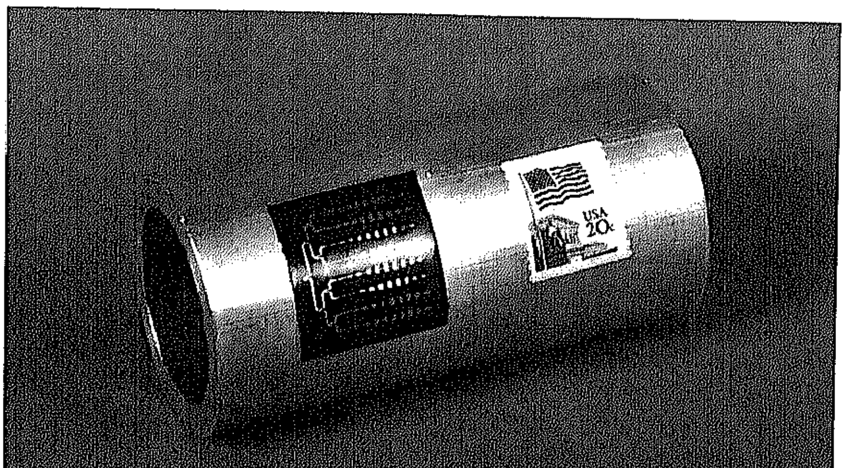


Fig. 6 — Conformal antenna research yielded techniques to photolithographic millimeter wave antennae which do not degrade aerodynamic performance

and cost of systems that transmit, receive, and process information in the form of speech, radio frequencies, image radar, or other modes. Research is supported in the areas of image processing; multidimensional digital signal processing in multisignal interference and jamming environments; and adaptive, optimal, and nonlinear signal processing. There is also interest in hybrid analog/digital processor systems, possibly involving optical/superconducting elements for use with VHSIC-type systems.

Methodologies are sought for enhancing performance, reliability, efficiency, and maintainability of electronic systems at the integrated circuit subsystem and system levels. At the integrated circuit level, the emphasis will be on obtaining basic knowledge and developing design rules to exploit benefits gained from reduced component size and to minimize disadvantages caused by physical constraints. At the subsystem level, the emphasis will be on the development of sophisticated subsystems that process, transmit, recover, enhance, and protect analog and digital information with a variety of specific characteristics. At the system level, the emphasis will be on the achievement of maintainable and reliable large scale systems and on the design of active performance monitoring techniques. At all levels, techniques resulting in efficient utilization of the available resources are sought.

Chemistry

The research programs include, but are not limited to, chemical and biological defense, laser chemistry, electrochemistry, chemical processing, ordered polymers, electroactive polymers, and energetic materials. Some of these programs are closely related to ongoing research in other disciplines, such as materials, electronics, and energy conversion.

Chemical and Biological Defense

This program provides fundamental information and new concepts in support of new or improved defensive systems against the chemical and biological (CB) warfare threat and a sound deterrence system to the use of chemical munitions. It also supports research in aerosol and obscuration sciences to meet the Army's requirements for smokes and obscurants. New concepts and a stronger scientific basis are needed for exploring novel approaches to protecting individuals and groups from chemical and biological agents and detecting traces of such agents; decontaminating people, structures, and supplies, and preventing their contamination; and developing training systems.

Laser Chemistry

Research in this area concentrates on laser chemistry as a revolutionary means of synthesizing, purifying, separating, and characterizing chemicals and materials. Lasers can accelerate the rates of chemical reactions manyfold, and the purity of laser light can be used to selectively control the course of chemical reactions. In addition, studies are directed toward chemically producing coherent radiation, especially in new chemical laser systems that will emit in the visible spectral region.

Electrochemistry

DoD has supported basic research in lithium and other high energy batteries for several years. Recently, patents have been awarded for lithium batteries that are rechargeable at room temperature, have high specific energies, and are much lighter than comparable lead-acid batteries. Fundamental research will continue to be sponsored in modifying electrodes, in new solid and fused salt electrolytes, in ion transport, and in processes occurring at a wide variety of electrode surfaces. Photoelectrochemical devices, new materials for rechargeable batteries, and new techniques for studying electrodes will be required to support further advances in high energy generation and storage technologies.

Chemical Processing

Traditional processing methods for ceramics, glass, and composites greatly limit DoD's ability to produce highly reliable products for use in severe environments. New chemical approaches based on inorganic, organic, and polymer chemistry offer opportunities for the low temperature processing of high performance ceramics and glass that are predictable and have controlled microstructures. These approaches include sol-gel processing, synthesizing and converting preceramic organometallic polymers, and using colloid chemistry to prepare high temperature bulk materials, powders, and fibers.

Ordered Polymers

Ordered polymers, which are produced from liquid crystalline solutions and melts, have extended rigid chain structures, whereas the more conventional polymers have flexible molecular chains. Film and fiber form of these polymers have demonstrated superior mechanical and thermal properties. Currently, researchers are studying these polymers for use in molecular composites in which rigid molecular chains reinforce a

flexible matrix of the same polymer. These molecular composites are the analog of chopped fiber reinforced macrocomposites. Successful research in polymer theory was based on the active participation of the DoD-supported 1974 Nobel laureate, P. J. Flory, of Stanford University, and the application of his statistical thermodynamic theory of liquid crystallinity in polymers. This technology is opening up a new research frontier in polymer science.

Electroactive Polymers

Electroactive polymers are opening new approaches for developing solid state devices. These polymers display a broad range of electrical conductivity and a high degree of anisotropy, which is reflected in their electrical and optical properties. Nonlinear optical polymers are demonstrating very high nonlinear optical responses and will be the basis for new materials for optical signal processing, computing, and other applications.

Energetic Materials

This important area of DoD research is directed toward understanding the chemistry of new and more energetic materials for propellants and explosives. Of equal importance is research which will lead to reduced hazards of energetic material. A DoD-sponsored program that investigated boranes resulted in the 1976 Nobel prize in Chemistry for W. N. Lipscomb of Harvard University. In addition, DoD support for H. C. Brown of Purdue University in boron-hydride chemistry research resulted in his receiving the Nobel prize 3 years later. Current research is emphasizing new techniques for synthesizing and producing new materials, studies of reactivity of the new materials, and studies of crystal chemicals.

Mathematical Sciences

The powerful techniques and creative insights that come from mathematics research play an increasingly important role in military problems in engineering, in planning and developing new systems, and in management. Among functional areas, specific use of mathematics research is noted in vehicle and weapon control; manpower planning and logistics scheduling; reliability and quality control; command control systems; signal processing for detection and tracking; control of air, land, and seaborne vehicles and weapons; remote sensors and surveillance; strategic planning; information systems and intelligence; and a host of specific scientific investigations that rely on mathematical and statistical methods. Recent reviews of the state of mathematics in the United States have pointed out both the leading role of DoD in this country's mathematics research and its contribution to better military effectiveness. Sometimes this occurs in a little-noticed and indirect fashion. Thus, the National Research Council, Renewing U.S. Mathematics (National Academy Press, Washington, 1984) noted that: "In national defense, the replacement of experimentation by numerical modeling, made possible by...dramatic improvements in mathematical algorithms, has resulted in great savings and...improvement in the quality of weapons design." The DoD basic research in mathematics is described in the following five categories.

Applied Analysis

Major research efforts are devoted to development of new and more powerful analytical methods of understanding real systems and their operations. Specific emphasis is in the understanding of multidimensional unsteady time-dependent physical and engineering processes such as wave propagation, structural mechanics, aerodynamics, hydrodynamics, turbulence, and shock waves. These methods become the mathematical tools used to discover and express in rigorous mathematical equations the basic relationships and laws of mechanics, physics, system control, and behavior.

Much of the research emphasizes development of solution methods for differential and integral equations as an essential tool, with advanced work in stability theory, the qualitative theory of dynamic systems, mathematical inverse and scattering problems, and the emerging techniques of robust stochastic and adaptive controls. Most of this research is motivated by the need both for new theories and for efficient computer programs to test the theories on real world problems. For example, better inverse methods are needed to infer the structure of ocean currents, eddies, cusps, boundary layers, and bottom reflection from the wealth of observations of recorded sounds received through that complex, ever-changing medium. Accurate estimates of submarine location depend crucially on such calculations. Development of fast algorithms for the solution of inverse problems will also enhance our understanding of high energy laser transmission, electromagentic propagation and imaging, acoustical, seismic detection, and atmospheric scattering problems.

Numerical Analysis and Computational Mathematics

Numerical solution methods for linear and nonlinear partial differential equations have been developed for a variety of atmospheric models and engineering problems. These include development of reliable predictive models and quantitative procedures using modern high-speed computers for the armor/anti-armor design, propulsion dynamics, and effective high performance explosives. Numerical linear algebra and adaptive methods are investigated, especially for geophysics and vehicle design problems. The pioneering work in Large Scale Scientific Computing (LSSC) and Very Large Scale Integrated (VLSI) Circuit Architectures is especially important. This work in computational analysis is providing mathematical bases for designers and

future users of the exciting special purpose algorithms and parallel processors now feasible with the next generation supercomputers. Figure 7 illustrates new architecture, which is called a systolic array. Data flow in a systolic system is (unlike linear, assembly line processing) in multiple directions. A computer with this architectural structure will be able to combine large amounts of data from streams of inputs, as shown, and process them in parallel operations. The hexagonal array structure is well suited to matrix operations such as multiplication of band matrices.

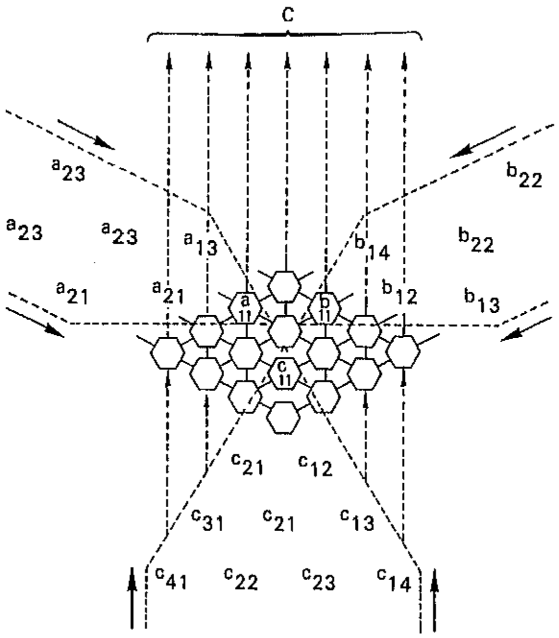


Fig. 7 — The hex-connected systolic array for matrix multiplication. Each element of the array multiplies the "a" variable by the "b" variable and adds it to the "c" variable. The computation time is dramatically reduced from n^2 steps to n steps.

Statistics and Probability

Research here is related to the broad issues of signal processing; reliability and quality assurance; inference from large, nonhomogeneous and nonindependent samples; and other statistical methods. For the significant problems of military systems and particularly advanced electronics, there are new statistical methods to reduce the cost and increase the reliability of weapons, sensors, vehicles, and communication networks. Computational statistics is a new field that is developing innovative statistical techniques not previously thought feasible. Research in this field seeks efficiency in the use of the very large data sets produced by modern sensors, which can be reduced to meaningful inferences because the new methods exploit the computational power of modern computers. Exploratory data analysis is another particular topic of interest in improving the ways in which data are assessed, aggregated, and interpreted when little is known about data *a priori.* New work is under way in learning and memory, and in statistical modeling of phenomena such as images from satellite-based remote sensors. Stochastic methods to treat uncertainties, both in physical and human decision systems, are examined in many tasks within the probability area. Surveillance, planning, weapons testing, war-gaming, and personnel-manpower problems are among the functional areas of application.

Clustering and projection-pursuit methods for high-dimensional data are a promising area of research. Currently, there is growing emphasis on fundamental research in the sciences of classification, clustering, multivariate data analysis, taxonomy, discriminant analysis, and decomposition methods (all of which divide data, techniques, and even abstract ideas themselves into categories of more or less homogenous subgroups where rigorous analysis and inference can then be carried out). The reason is that classification problems occur in every field, from organization theory to specific electronic and neural system problems. Moreover, "natural" classification (such as in ordinary language) is not enough. For example, clustering needs to be performed to reduce the huge volume of data of many different kinds (both numerical and text) that constitute all our knowledge and clues when surveillance and intelligence systems try to guess an enemy's locations, movements, and intentions. Mathematical methods enabling us to go beyond obvious divisions and to go beyond the 3-dimensional world, to include all the qualitative cues and other characteristics associated with physical location, are a major concern at the frontier of science, as well as of military planning and

operations. One new way is to use projection-pursuit methods, an extension of the standard statistical technique of linear regression. These methods constitute a more flexible way of searching for an optimal representation, when the data represent nonlinear phenomena, and some of the information germane to a problem consists only of qualitative orderings rather then specific numerical values of parameters. Such nonparametric probability density function estimators also can serve as a graphical tool for looking at data.

In seismic and acoustic signal processing, significant evidence of non-Gaussian processes has been found to characterize ocean noise, contrary to traditional assumptions. Figure 8 illustrates the densities found from acoustic noise recordings, when density estimates are calculated by using a fixed kernel algorithm. Submarine detection is a potential application.

Decision Sciences

Basic research in the decision science disciplines, from game theory to operations research and control system models, is leading to applications in every functional area of defense planning and operations. Major uses are found in weapons systems investment choices; tactical doctrine; strategic planning; and efficient design of logistics and manpower systems. Techniques of war gaming, large-scale simulation, and mathematical optimization are the basic tools of DoD studies and analyses. A particular area of major and growing interest is multiple criteria decision models, involving new quantitative measures in utility and value theory that incorporate risk-taking preferences. The complexity and vulnerability of command, control, and communications systems have created major problems for military organizations. Evidence of the complexities of command decision making has stimulated new mathematical work using control theory and other sophisticated techniques to model decentralized systems with distributed data. The resulting mathematical models and simulations are applied to evaluate overall theatre and tactical force levels, as well as to the more specific sensor data fusion and threat assessment functions. In addition to decision aids, decision science research includes fundamental work on principles for long-range planning, resource allocation and management, in the particular environment of future uncertainty that national security decisions must address. It seeks a scientific basis or integrating framework for the coordination of all decisions, both short- and long-range, in all parts of a large system.

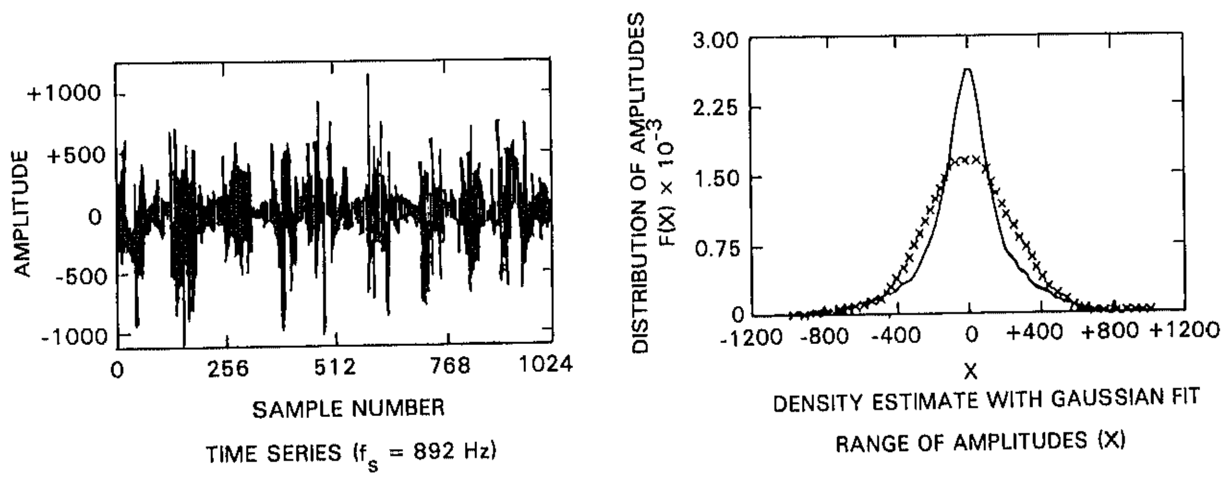


Fig. 8 — Upper trace depicts typical ocean noise data originating in the continential margin, shows an intensive pattern of impulsive noise (the large spikes) which are biological in origin. Such noise violates the typical Gaussian assumption for the background noise. Many currently used algorithms, while effective at high signal-to-noise ratios, degrade unpredictably as intensity drops. The best Gaussian fit (the crosses) to the actual density curve indicates the nature of the mismatch for the data set.

Theoretical Mathematics

A variety of research tasks within classical and modern mathematics topics of a theoretical nature are included in the programs of all three military services. In particular, discrete mathematics is emphasized because of its importance for analysis of large-scale systems, communications networks, and information systems. Algebraic geometry, automata theory, and graph theory are being developed, partly to gain understanding of the limits of feasibility in design of large systems. A specific example of opportunities for use of theoretical mathematics is found in application of topology to the classification of molecular structures in chemistry. Mathematical research in coding and computability contributes to computer science.

Mathematics Research Center

As part of the mathematical sciences program, the Army Research Office supports a center which serves as a national focal point for comprehensive, integrated, fundamental research programs. An integral part of the center is a vigorous postdoctoral and junior and senior visitors program. The center also provides educational and technical assistance to the U.S. Army.

Computer Sciences

DoD has relied heavily on computer technology since World War II; the unique and demanding needs associated with computers motivate a strong program of basic computer science research. Computer science research funded by DoD has had a major impact on our national security, and spin-off benefits from that work have significantly influenced the U.S. computer industry. Some areas of accomplishment are: the development of time-sharing; higher level languages; packet-switched communications and distributed processing; artificial intelligence technology; supercomputers, such as multiprocessor architectures; interactive computer graphics; and microelectronics, including design tools. Taken as a whole, the Department of Defense's basic research program in computer science is the largest and most varied program of its kind, with an outstanding record of providing capabilities for defense, as well as aiding the economic strength of the Nation.

Communication and Distributed Processing

A science of computer-based communications and distributed processing will make possible more survivable computing in view of outside threats and of both hardware and software failures, and more efficient use of shared computing and communication resources. This basic research is a direct product of previous work on circuit switching and packet-switching theory, routing algorithms, and time-sharing scheduling algorithms. Current concerns include the areas of internetwork protocols; multimedia networks; key distribution and network security; distributed operating system design; distributed data base and methods of assuring integrity of very large, redundant data bases; and a variety of the underlying theoretical issues in, for instance, information theory. This area of basic research has had a particularly large impact on practical DoD systems, including the development of the ARPANET and packet radio.

Computer Architecture

Essentially all computers in use throughout the world have a similar architecture, consisting of a single processor that follows the instructions in a computer memory. As such, these so-called von Neumann machines can do one action at a time, sequentially reading and executing a sequence of instructions. Examination of computer programs written over the past 40 years reveals, more often than not, the underlying programs and algorithms have the opportunity for concurrent calculation of different parts of the work, thus indicating a potential for speeding up the total process by a factor of, from a hundred to a million, depending on the particular situation. This is a tremendous opportunity—at the lower end of that range, it indicates a possibility of completing in a day what previously took 3 months, and at the upper end of that range, it means that a calculation might be completed in an hour when it might otherwise have taken a century. The limiting factor is the availability and effective use of computers that can do many parts of a calculation concurrently, namely multiprocessor architectures. The issues that must be resolved before this promise becomes a reality are formidable. How many processors? How large should the processors be? How should they be connected? How can a computer system containing between a hundred and a million processors be programmed? What are efficient algorithms for using such multiprocessor architectures, so that as more and more processors are added to the systems, an approximately linear speedup in performance is achieved? How can the division of a program be automated among a large number of processors in a multiprocessor system, to relieve the programmer of an impossible burden? What kinds of programs will be speeded up on multiprocessor architectures? There is a significant DoD effort in the area of multiprocessor architectures and algorithms that can lead to a quantum leap in our capabilities during the coming decade.

Artificial Intelligence

DoD has been supporting the advance of artificial intelligence for about 25 years, and that investment has led to significant advances in the state-of-the-art, practical applications both within DoD and in the civilian sector, and a rapidly growing segment of the U.S. computer industry. The field has been concerned with fundamental issues, such as problem solving, inference making, learning, creativity, and common sense reasoning, as well as more applied areas such as speech understanding, natural language understanding, and image understanding, or vision. Recently, excitement is growing about the development and use of expert system technology. Sets of techniques and methods that represent and use the knowledge and heuristic rules-of-thumb of experts in some domain in a computer system are emerging. The overall goal is to improve stress performance by dealing with large quantities of information and data, operating reliably under stress, combining disparate types of expertise, and broadening the availability of expertise in the face of limited manpower. The DoD program in artificial intelligence will continue, with increased technology transfer between fundamental work primarily done in universities and more applied work in the U.S. computer industry.

Software Production

DoD spends billions of dollars each year on the production and maintainance of large software systems; there is every incentive to reduce that expenditure while, if possible, increasing the quality of the computer programs that are written. In the near future, systems one to two orders of magnitude larger than ever before will be necessary, and without fundamental advances in the way software is produced and maintained. Achieving success will involve significant risks. To add to the difficulty, many DoD activities involve classified information, so that systems must be "secure" or "trusted." The DoD basic research programs in software are addressing a variety of approaches to the problem: very high level language; specification languages, and automatic program verification using formal logic to check for consistency and correctness; the use of so-called object bases containing specifications, descriptions, and programs organized for ease of reuse; graphic techniques to aid the programmer team in designing and producing software; and computer-based management tools to aid production process. These efforts have a natural focus in a programming environment to support the use of Ada, the DoD-developed programming language.

Interactive Computer Graphics

Interactive computer graphics technology has been of critical importance to DoD for a variety of applications, including training simulators (e.g., aircraft; command and control displays), situation assessment, and for computer-aided design system. The basic research thrusts have been in the areas of algorithms for the production of pictures, computer architectures that can effectively support those algorithms, data base structures that can be economically built and modified, and fundamental mathematics of techniques, such as texture production using fractals. In addition to providing systems for DoD needs, this basic research has had impact throughout the U.S. computer industry, and even more recently, within the motion picture industry.

CAD/CAM and Robotics

DoD has special needs in the areas of computer-aided design (CAD) and computer-aided manufacturing (CAM), particularly with respect to the need to rapidly prototype small quantities of parts and microelectronic circuits. These requirements have provided the impetus for basic research on CAD/CAM methods and techniques, with particular application in the VLSI arena. Further, robotics research has been supported both from the viewpoint of "conventional" manufacturing and defense needs for teleoperated systems and autonomous systems. Basic research areas have included the design of languages for interacting with robotic systems, algorithms for the real time control of many-

degree-of-freedom robotic devices, and application of artificial intelligence techniques for integrating robotics and sensory modalities, such as vision.

Man-Machine Interaction

DoD is particularly concerned with the design of computer systems for effective man-machine interaction. DoD experiences a large turnover in DoD personnel, training costs are high, and errors made during a military operation could be catastrophic. The basic research program in man-machine interaction, or man-machine relations, has been concerned with the integration of newly available graphics, speech, and natural language capabilities, as well as the design of an essentially new vocabulary for man-machine interfaces that are so natural that they require essentially no instruction. Some of that past work has influenced the design of current personal computer and office automation systems.

Embedded Computing

Embedded computers are in many DoD systems, including aircraft, "smart" munitions, and satellites. These systems present special requirements for low volume and low power computing technology, and extremely high reliability of both hardware and software. Basic research in microelectronics, packaging, batteries, redundant computer architectures, and software engineering address these concerns.

Engineering Sciences

- **Fluid Mechanics**
- **Energy Conversion**
- **Structures**
- **Materials**
- **Automation Sciences**

Fluid Mechanics

Research in fluid mechanics provides the underlying basis for design of external flow systems, including aircraft, rotorcraft, naval craft, missiles, projectiles, and internal flow systems, such as engines and lasers. Major thrusts involve understanding and modeling turbulence, developing computational fluid dynamics methods for steady and time-dependent flows, and understanding steady and time-dependent separated flows.

Fluid Physics

Turbulent shear layers on surfaces have a crucial role in the performance of DoD vehicles and weapon systems. A major emphasis in fundamental fluid physics is understanding the origin and evolution of turbulence structure in shear flows. The importance of understanding turbulence structures is illustrated in Fig. 9, which shows that the turbulence burst process accounts for the major portion of skin friction drag on a surface in a fluid stream. Extensive use is made of advanced experimental diagnostic techniques and large scale numerical computations to identify and characterize turbulent structures and their interactions in free and bounded shear layers.

Alternatives to statistical turbulence modeling concepts, which can account for deterministic features, are considered for describing the structure of turbulent boundary layers. One example involves exploring the feasibility of using mathematical chaos concepts to describe turbulence events and tubulence modification. In addition to improved understanding of the naturally occurring structures, new methods are sought for passively, actively, or interactively controlling turbulence characteristics for such ultimate purposes as reducing drag or enhancing fluid mixing. One example of recent work on turbulence control is a large eddy breakup device which inhibits the turbulence bursting process in boundary layers (see Fig. 9) and lowers the associated surface shear stress (skin friction).

Another major objective is understanding the behavior of attached and separated unsteady shear layers affected by time-dependent boundary conditions. This combined analytical, experimental, and computational research program is oriented toward productively exploiting the characteristics of unsteady flows to improve aerodynamic maneuverability and enhance performance of flight vehicles. Current research involves studies of dynamic stall on 2- and 3-dimensional lifting surfaces and characteristics of driven, unsteady separated flows.

Other research in fluid physics includes multidisciplinary hydrodynamic studies in areas such as drag and noise reduction by means of

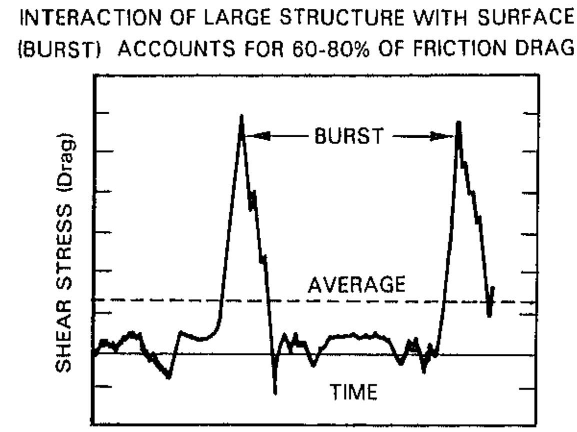


Fig. 9 — Turbulent shear stresses in boundary layers of flight vehicles contribute to aerodynamic drag. Intermittent turbulent bursts occur when fluid near the surface is suddenly ejected into the outer boundary layer flow. Such bursts produce a major part of skin friction drag.

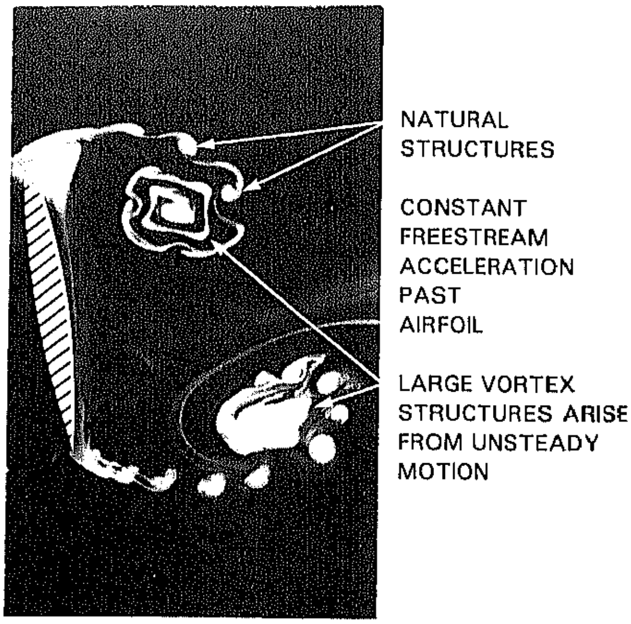


Fig. 10 — Aerodynamic surfaces can generate unusually large forces under unsteady flow conditions. Here, a fixed air foil at high angle of attack is subjected to a rapid increase in air speed. Large scale energetic vortex structures are formed which produce forces significantly higher than those in steady flow.

additives, injectants, and energy transport. A program in hydroacoustics focuses on the basic mechanisms of the fluid dynamics associated with noise generated by the turbulent boundary layer flow, especially in the low wave number regime.

Aerodynamics of Aircraft, Missiles, and Projectiles

Separation and control of the boundary layers, control of the vortical flow for closely coupled aircraft or missile configurations, jet mixing and jet/surface interactions, shock/boundary layer interactions, unsteady and separated flows associated with maneuvering flight, and jet plume/afterbody interactions are of interest. Visualization of such flows, as in color schlieren photography, aids in formulating and verifying theories and models. Advanced computational techniques for solving Euler and Navier-Stokes equations are being developed to provide insight into 3-dimensional phenomena, such as the shed vortex structure, and to provide more powerful design and analysis tools. Important research areas addressed in computational fluid dynamics include establishment of efficient and robust numerical procedures that take advantage of new computer architectures and methods for generating computational grids for complex 3-dimensional bodies, such as aircraft and missiles.

A new program has been initiated to investigate the basic aerodynamics of wings at low speed and low Reynolds numbers based on wing cord. Emphasis is on 3-dimensional and time-dependent flow fields. The separation and reattachment of laminar boundary layers, the transition of the boundary layer, and the production of turbulence is of special interest. Other new research focuses on investigation of unsteady, separated flows generated by large amplitude motions of the boundary surfaces which can occur for highly maneuverable aircraft and missiles (see Fig. 10). This research centers on methods for characterizing and predicting these flows and control concepts for generating organized, time-dependent separated flows.

Aerodynamics of Rotary Wing Aircraft (Rotorcraft)

To increase the performance, reliability, and safety of rotorcraft and to lower costs, forces and moments produced in hover and in forward flight

must be understood and predicted. To achieve these goals and similar goals related to noise, vibration, structural dynamics, and aeroelasticity of rotorcraft, centers of excellence in rotary wing aircraft technology were established. These centers, which augment the industrial, academic, and governmental scientific base, are contributing to a concerted, coordinated effort to understand unsteady, turbulent boundary layers; 3-dimensional separation flow patterns; unsteady, transonic tip flow; vortex dynamics; and rotor systems and wakes. Detailed wake geometry is required for predicting accurate blade loads in hover, hence, hover performance. Examples of ongoing research include the analytical modeling of a rotor free wake in forward flight, studies of blade-vortex interaction using paneling techniques for the lifting surface, experimental efforts to generate controlled vortex flows in a shock tube, detailed measurements of Reynolds stresses in an unsteady separating boundary layer, and a new formulation for a turbulence model that will treat strong adverse pressure gradients and unsteady free streams.

Hydrodynamics

Hydrodynamic research relates primarily to the hydrodynamics of ships and submersibles and to geophysical fluid mechanics. Areas of emphasis include nonlinear, free-surface phenomena interacting with moving bodies, nonlinear ship response to waves, local flow behavior in the bow and stern regions, boundary layer and wake flows, propeller hydrodynamics and cavitation. A new program has been initiated on the complex hydrodynamic and hydroacoustic interactions between hull flow fields and propulsors. Particular emphasis is on the role of the spatial and temporal structure of turbulent and vortical flows on the hydrodynamic and hydroacoustic performance of the propulsor and on unsteady hydrodynamic loads on the vehicle hull. Geophysical phenomena are considered in relation to their interactions with vehicle-generated disturbances and wakes at and below the sea surface. The evolution of the wake, effects of ocean stratification, effects of turbulence, wind-wave interactions, and transport processes at the air-sea surface are of specific concern. Emphasis is on controlled laboratory-scale experiments and detailed modeling.

Internal Fluid Dynamics

This research focuses on investigations to improve the understanding of and the capability to predict compressible viscous flow in gas turbine engines. Flows in internal passages characteristic of inlets, axial flow compressors, and turbines are of primary interest. To this end, researchers must understand how viscosity, turbulence, compressibility, nonsteadiness, and temperature variation affect this viscous flow. For compressors, the technological opportunities include improvement in blade durability and increases in compressor efficiency, which translate directly into improved specific fuel consumption. Specific examples of compressor-related research include exploration of aerodynamic loading, prediction methods for analyzing forced response of compressor blades, and determination of the role of flow instabilities on compressor efficiency loss. The technological goal of research in turbine flows is to increase engine performance by allowing for higher turbine inlet temperatures. The research focuses on generating methods for accurately predicting heat transfer, including methods for predicting the effectiveness of active surface cooling, in the complex turbine flow environment. Research is conducted on the effect of blade erosion on performance. Flows in the internal passages of high energy lasers, including the effects of the turbulent structure of shear layers on optical characteristics of the laser beam, are also of interest.

Energy Conversion

Energy conversion encompasses the production of useful propulsion and power from either fuel or remote sources. The broadly based research anticipates the needs of aircraft engines, rocket motors, vehicle engines, power units, fuels, propellants, and explosives. Often large premiums are placed on extending energy density while not compromising reliability and safety. Advances in energy conversion tend to be multidisciplinary. For example, research on new metal fuels includes chemical synthesis, surface science, combustion, spectroscopy, and fluid mechanics.

Energetic Materials

Explosives, rocket propellants, and gun propellants consist primarily of materials that release large amounts of energy per unit volume or mass, are stable, are safe, produce an acceptable signature to avoid detection, and are economical to implement. In addition, many applications require that these materials have good structural properties under high acceleration loadings over a wide range of temperature extremes. The relative importance of the above characteristics is application dependent; often, an advancement that improves one property detracts from the others. Forefront research is pursuing new compounds that have the specific combinations of the desirable properties. Once a new class of materials with the desired properties is isolated, research is directed at understanding their decomposition mechanisms, structural properties, aging processes, and hazards.

Recently, investigations into the synthesis of energetic ingredients were augmented; complementary research is needed to improve the characterization techniques for these higher energy (and more temperamental) ingredients and propellants. Emphasis is on new energetic monomers and polymers for use as binders in composite propellants. For rocket and gun propellants, chemical control of nitramine burning rate has been elusive. Recent approaches pursue burning rate control through molecular modification. Plasticizers that increase burning rates of conventional propellants may unevenly redistribute themselves, degrade bonding interfaces, and produce unacceptable hazards. Advances in instrumentation and computational models are needed to guide the synthesis of new compounds and to accelerate the assessment of their characterization.

Rocket Propulsion

Present and future rocket propulsion systems present critical challenges that are not addressed adequately by present technologies. As the conventional propulsion technology matures, the need persists to attain yet another round of performance gains. Also, broad classes of problems (e.g., combustion instability, service life, signature, low-temperature structural integrity, lightweight thermal protection) are never solved entirely and recur often as important considerations prior to propulsion system qualification. Many phenomena, not explained adequately, are accommodated only by specific designs. Periodically, this lack of understanding is the precursor to major setbacks. Clearly, rocket motor processes present scientific challenges suggesting that properly conceived research will lead to higher performance, reduced risk, lower development costs, and longer service life.

More attention is being given to research relating to nonconventional primary propulsion for space. Nonconventional propulsion concepts periodically receive attention but invariably the propulsion systems chosen have been adaptations or extensions of conventional liquid and solid rocket technology. The dominant consideration in previous years was that DoD missions could be performed using conventional chemical propulsion. Consequently, major initiatives to provide

technology and to overcome specific barriers could not be justified. The recent emphasis on space and the reusable launch vehicle capability to low Earth orbit present new considerations for advanced propulsion for orbit transfer. Transferring large payloads using conventional propulsion imposes severe limitations on the missions. For example, 75% of the mass delivered to low Earth orbit may be the chemical propulsion system required to raise the other 25% (i.e., the active payload) to geosynchronous Earth orbit; nonconventional propulsion offers the promise of reversing this ratio of propulsion and payload masses.

The fundamental processes related to beamed energy and solar propulsion include radiation transmission and absorption in flowing media, plasma initiation, and chamber configurations. The immediate advantage of beamed and solar energy is high specific impulses obtained by using low molecular weight working fluids heated by external power sources to temperatures greatly above combustion gas temperatures. The premise of the beamed energy approach is that suitable megawatt laser sources will be available and justified for applications other than propulsion. Recent studies support the thesis that ground based lasers operating at suitable short wave lengths will enable attractive transmission efficiencies and compact collection optics. Until recently, mechanistic understanding did not permit the existence of thin absorption regions and stable plasma flows to be predicted. As shown in Fig. 11, a continuous (1.5 kW) carbon dioxide laser was used to create a laser sustained plasma in a cylindrical quartz flow channel. The convective flowfield surrounding the plasma was controlled after understanding the interactions among the flow field, channel geometry, and radiation absorption.

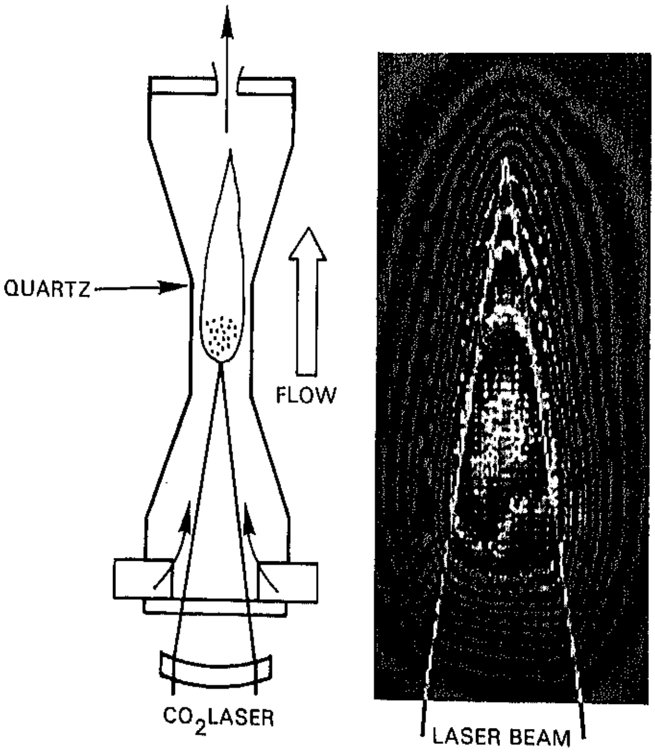


Fig. 11 – Diagram of apparatus for beaming laser radiation into a flowfield. Laser radiation focused into flowing gases ignites and sustains high energy density plasma. Steady isothermal patterns demonstrate that the beamed energy plasmas can be stabilized over a range of geometries and flow conditions.

The research relating to electric propulsion emphasizes concepts which lend themselves to sustained operation at megawatt power levels. This represents a major departure from millinewton thrust, pulse-mode electric considered for station keeping or planetary probes. Present mission analyses are exploring the premise of the dual-mode megawatt nuclear power supply which is onboard for both the main mission and for propulsion power. Thus, propulsion does not take the weight penalty for the power source. When large total impulses are required, thruster mass is small compared to the fuel mass; thus, a premium is placed on increasing fuel efficiencies and the low thrust densities of the thrusters become unimportant. Electrode and insulator lifetimes have been identified as primary barriers to sustained, high power density operation. Accordingly, a major portion of the research will be directed at mass loss mechanisms and conditions leading to abusive environments and inefficient operation.

Ample opportunity exists for new research approaches. Good progress is being made on understanding the origins of instability; more attention must be given to the mechanisms of deliberate suppression. The remarkable advances in optical diagnostic techniques present new approaches to investigate plasma flows which must be understood and controlled under magnetoplasmadynamic and beamed energy conditions. Research on life limiting processes will benefit from advances in remote sensing of surface temperatures, composition, and structure. Future missions will present entirely new autonomous operation challenges; a theoretical basis must be established to anticipate and guide the advances in sensors, adaptive control, thruster configuration options, etc. Sustained megawatt operation of space thrusters will be limited by the inability to reject heat; research is needed to enable advances in lightweight radiators and thermal management systems.

Airbreathing Propulsion

Research into the dynamics of airbreathing propulsion is concerned with generating propulsive power more efficiently and reliably. Multidisciplinary research is directed at understanding and controlling the highly coupled fluid transport processes, thermodynamics, and chemical reactions relevant to propulsion systems for aircraft, missiles, ships, and land vehicles. Propulsion devices include gas turbines, ramjet engines, and reciprocating engines. Closed-loop, liquid metal combustion processes will be utilized in underwater propulsion systems. Areas of scientific investigation include large- and small-scale turbulent mixing, the dynamics of liquid and slurry fuel sprays, control of exhaust particulates, and the modification of metal fuels to achieve rapid combustion. Advances are sought to achieve more uniform combustion; to control exhaust emissions; to achieve hypersonic flight utilizing combustion of solid fuels in airbreathing systems; and to achieve hypersonic flight utilizing supersonic combustion in propulsion systems. The combustion instability problem associated with compact ramjets is of immediate interest.

In view of the eventual scarcity of domestic fuels and the undesirability of the United States relying on foreign fuels, research is needed to achieve more efficient diesel and turbine engines for land vehicles with multifuel capability. Developing accurate and detailed combustion and thermal models of diesel engines is particularly difficult. Fuel injection, mixing, and combustion processes cause the environment within the diesel engine to be transient and not spatially and temporally homogeneous. Because of the large soot-particle concentrations present during the combustion cycle, heat transfer to chamber surfaces includes convective and radiative components. Combustion occurs near the thermodynamic critical state of the fuel. Presently, research is under way to understand better such processes as the formation of fuel spray, turbulence of reacting flows, and the formation and destruction of soot. Figure 12 shows an example of chemical modification of a flame.

Electric Power

Research in power generation is needed for more efficient and improved vehicle and auxiliary

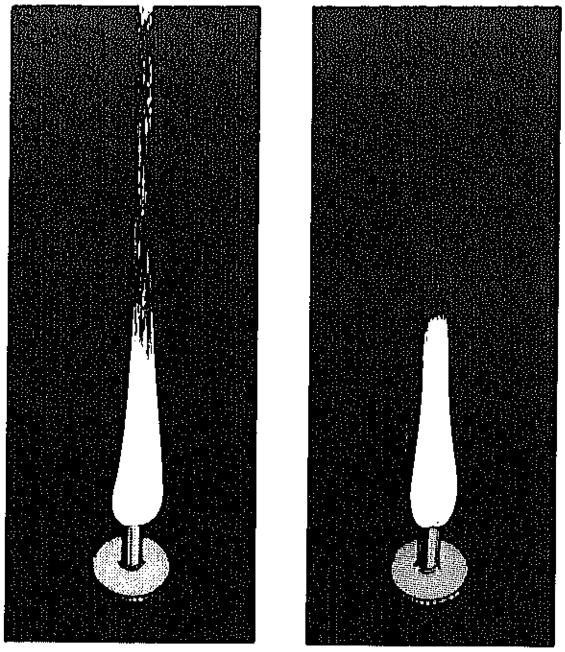


Fig. 12 – The role of metallic salts in inhibiting soot formation is providing insights into the mechanisms and, ultimately, the control of soot emissions

power systems for all types of land, sea, and air vehicles. In the area of pulsed power, research is under way to investigate the properties of high temperature, high pressure plasma for generating pulsed magnetohydrodynamic power. Emphasis is on understanding and controlling the direct conversion of chemical and thermal energy into intense electrical energy. Currently, efforts are directed at innovative concepts to high power such as high repetition rate opening switches which are needed for inductive energy storage in compact configurations. Specifically, the chemical production of electron-attaching species and the electronic properties of unusual surface configurations are of interest. Also, techniques for controlling large electron densities and the conduction and electron emission characteristics of solids and surfaces with pressure, temperature, and magnetic fields, and electric fields are needed.

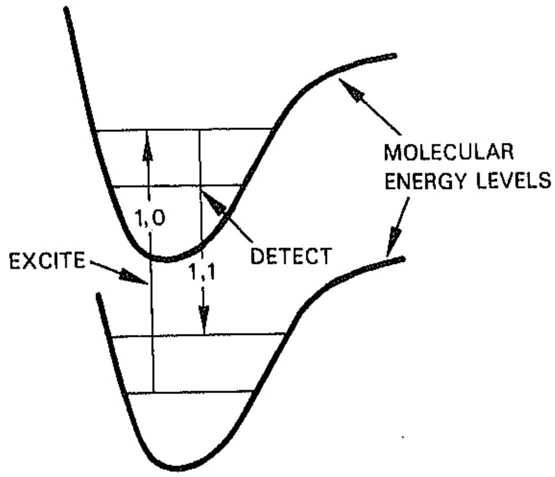
A closely related technology involves the electrical acceleration of projectiles to velocities several times greater than those achieved by conventional means. Toward that end, the concepts being pursued include electromagnetic effects to generate a propelling plasma and current carrying rails to electromagnetically propel a projectile.

Advanced Diagnostics

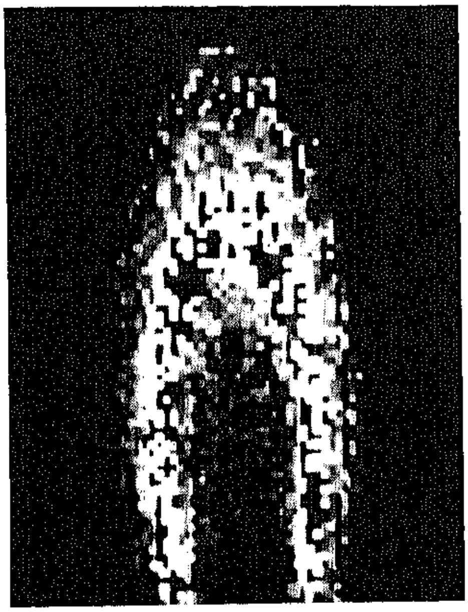
Diagnostic techniques for controlling and understanding reacting flows are being rapidly advanced. The national attention on laser-based techniques is rapidly achieving many "first-ever" measurements, for both laboratory and bench-test conditions. The successes will continue with the increasing capability of lasers, detectors, digital electronics, and fiber optics. Indeed, diagnostic advancements are integral goals of many of the sponsored energy conversion research programs.

Present and future propulsion, power, and laser systems present critical challenges not addressed adequately by present technologies. Opportunities exist for new approaches, e.g.,

- High performance systems often frustrate attempts to gain optical access. Non-optical, nonintrusive approaches are needed.
- The advent of quantitative flow visualization for turbulent reacting flows is presenting opportunities for theoretically treating and fully exploiting array data in such a way that reveals rapid evolution of flow structure, flame fronts, and instabilities.
- The anticipated requirements for adaptive control and for autonomous operation require major advances in sensing strategies, sensors, and diagnostics.
- Optical diagnostics should lead to new approaches for investigating plasma flows which must be understood and controlled under magnetoplasmadynamic and beamed energy conditions.



EXCITATION DETECTION STRATEGY FOR OH



DIGITAL SPECIES IMAGE OF OH
IN SOOTING FLAME

Fig. 13 — Diagnostic strategy overcomes laser scatter from particles in flames. Digital image of OH in sooting flame as an example of pulsed laser excitation (of a planar region) revealing the instantaneous spatial variations of chemical species.

As an example of a recent advancement, instantaneous flame species and temperature distributions were captured for 10,000 geometric points in planes through turbulent flames. As indicated in Fig. 13, the method utilizes one laser wavelength to excite fluorescence and another wavelength to detect the fluorescence. This overcomes the problems of scattering from particles. Not only is this the first time species concentration gradients have been measured in sooting flames, but also the data rates of 300 frames per second are more than an order of magnitude faster than for the previous methods attempted.

Structures

Research in structures provides the basis for the design of DoD systems, including methodology for stress analysis, modeling of material behavior, life prediction, and failure prediction under a broad range of loading environments. Major areas of interest include modeling of material, mechanical responses, structural damage growth and failure, structural dynamics and controls, impact response, blast effects, and stochastic modeling.

Mechanics of Materials

Research in the mechanics of materials deals with the modeling of the mechanical response of damaged and undamaged structural materials under the full range of load histories. The materials of primary interest include metals, polymeric and metal matrix composites, and geotechnic materials (such as concrete, soils, explosives, and rocket propellant materials). Specific areas of interest within the general scope of this research are described below:

Constitutive Relations—Constitutive relations are being developed to model nonlinear material stress and strain responses under general thermomechanical loading. For example, extensions to thermoviscoplasticity theory, which models material response as time and temperature dependent, are being used to analyze the structure of a high temperature propulsion system under thermomechanical fatigue. Shock or blast effects, mechanics of penetration, and processes of metal forming are under analysis using models including high strain rate effects. Research is being done on the interactions between plasmas and solids that occur when very high velocity projectiles are electromagnetically launched. Several programs address the development of constitutive relations, including distributed damage and material degradation. Another concern is the constitutive behavior of soils and an *in-situ* determination of properties that control constitutive behavior.

Fracture Mechanics and Fatigue—In an effort to improve the damage tolerance and durability of military structures, extensive research continues in fracture mechanics and the prediction of general damage growth in structural materials. Inelastic fracture is under study to understand more about the effects of overload and crack healing on fatigue in aircraft structures and to predict failure in geomaterial systems, such as runways, missile silos, and other hardened facilities. Studies of elastic-plastic and dynamic fracture of thick sections, such as those found in naval structures, tanks, and armor are emphasized.

An extensive program exists that investigates the mechanisms of fracture and develops models of damage for fixed and rotary wing aircraft composite laminates. New experimental techniques, such as vibrothermography and stereo X-ray, are used to carefully characterize the development of damage states of structures under static and dynamic loads. The inset in Fig. 14 illustrates some of the major damage mechanisms that occur in composite laminates. Recently,

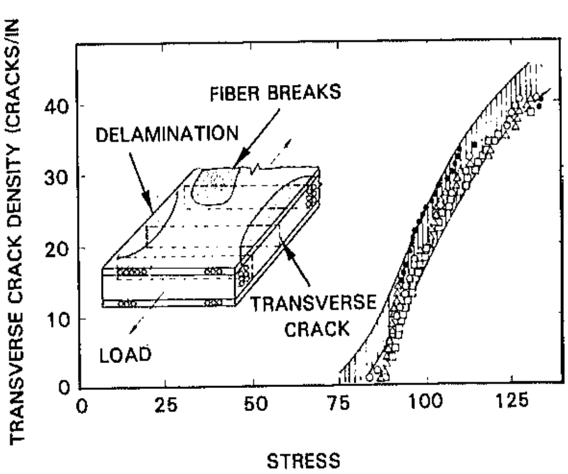


Fig. 14 — Monte-Carlo simulation (points on plot) of transverse crack density represents broad experimental trends (cross-hatched region)

basic fracture mechanics models for transverse matrix crack growth were developed. Figure 14 shows the simulation model results for transverse matrix crack density. Damage process zone models are under study for aircraft composite laminates and cementituous geocomposities, such as concrete. Basic experimental characterization and model development for damage processes are being performed for continuous fiber and particulate metal composites.

Probabilistic Fracture Analysis—To achieve optimum operational readiness, safety, and reliability of structures used by DoD, research is supported in probabilistic methods of characterizing and predicting fracture and fatigue failure. Emphasis is on stochastic modeling of the processes of damage growth. Figure 15 illustrates fatigue failure data for an aircraft aluminum alloy and compares the prediction of failure obtained from a new stochastic distribution model and a conventional Weibull distribution model. The substantially improved prediction of the early failure tail obtained from the stochastic distribution model will improve DoD's ability to predict and characterize early failure of structures.

Tribology—Tribology research is directed toward understanding fundamental phenomena related to friction, wear, and lubrication of seals,

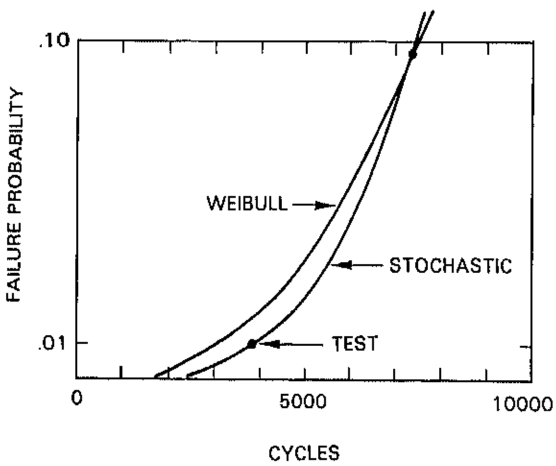


Fig. 15 — Stochastic approach predicts early fatigue failure more accurately than conventional distribution models. Research need is to better understand failure processes from stochastic modeling.

bearings, gears, and other high performance machinery components for enhanced lifetime, performance, and quietness. Analytical and experimental methods are under development to measure and predict temperature and stress at surfaces which are in rolling and sliding contact. For example, a numerical solution which can account for squeeze film effects and can predict lubricant cavitation and bearing load capacity has been developed to investigate dynamically loaded journal bearings. Fundamental mechanisms for the transfer of material films in rolling and sliding contact are studied as a function of the parameters of the materials. Improving materials and modifying the surface by melting the surface with lasers and implanting them with ions are considered as ways to improve the behavior of the material during friction and wear. Particular attention is paid to highly loaded rolling or sliding contract surfaces with application to quiet mechanical power transmission.

Structural Mechanics

Research in structural mechanics encompasses the basic methods of analyzing and designing structures so that they have adequate strength and are structurally stable under anticipated static and dynamic loads.

Dynamics and Vibration—Research on vibration and dynamic response of structures to applied loads covers a broad spectrum of programs from the control of low-speed traveling wave phenomena in large flexible spacecraft to studying high frequency resonant phenomena that occur in bladed disk assemblies of turbine engines. The dynamics of helicopter rotor blades and hubs are increasingly emphasized, especially the analysis of the aeroelasticity of the rotor blades and the dynamics of the coupling between rotor and fuselage with unsteady aerodynamics. Aeroelastic tailoring of composite laminates is being pursued for its potential application to fixed and rotary wing designs. Another program investigates the interaction between structure and fluid in the aeromechanical response of labyrinth seals commonly used in turbine propulsion systems.

A major new program addresses the dynamics of and the interaction between structure and control of large space structures. Stochastic structural modeling is being developed to describe the uncertain structural parameters of such structures when they are deployed or assembled in space. Methods of improving structural design are being researched to provide tools for efficiently designing the structure and control system integrally to achieve tight dimensional constraints during operation.

Shock and Impact—Numerous efforts are directed to the reaction to shock and impact loadings on military structures for land, sea, and air. These efforts range from studying the shock of gun firing, to studying the reaction of composite laminate structures to impact. Recently, a finite element shell analysis enabled the accomplishment of an impact response analysis of shell structures with large deformations well into post crippled behavior, as shown in Fig. 16. Research on blast effects include analyzing the effect of air blast on aircraft and land vehicles; the effects of underwater blast on shell structures, such as submarines; and the effects on surface and underground structures of blast waves that were transmitted through the soil.

Acoustic Excitation—The entire problem of acoustic excitation as it relates to the failure of DoD structures is of utmost importance. Structures, such as helicopters and propulsion systems, can fail because of acoustic fatigue. One major program addresses sound that radiates from submarines and noise signatures of helicopters.

Computational Methods—A large degree of freedom finite element analyses and a substantial research thrust in nonlinear systems in terms of material and geometric nonlinearities are supporting the impetus for the establishment of new computational methods. Improved accuracy criteria and convergence of computational techniques, stability studies, uniqueness of solutions, and boundary condition sensitivity of structures described by advanced constitutitve laws are of particular interest.

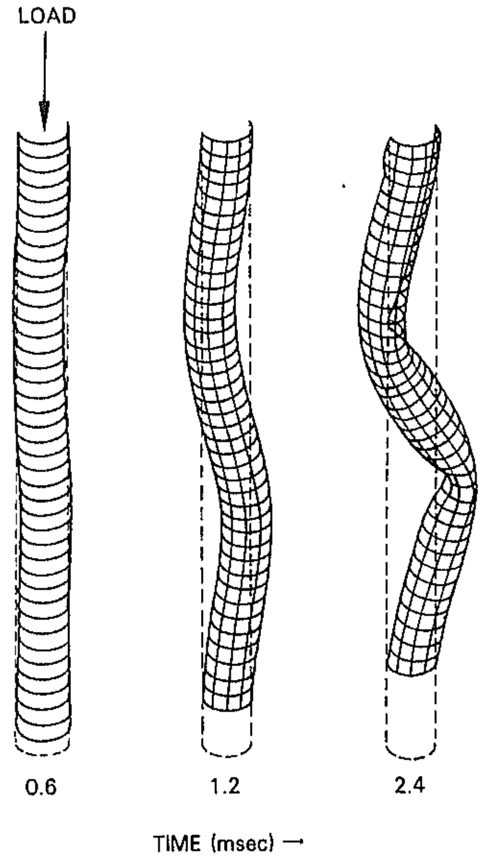


Fig. 16 — Current capability allows large deformation postbuckling computer simulation of impact loaded cylinder. Research is needed to predict such behavior for inhomogeneous anisotropic composite structures.

Materials

Research on materials relies on interactions among researchers in physics, chemistry, metallurgy, ceramics, geology, and engineering. The aim of this research is to discover the fundamental relationships that connect chemical composition, atomic and microscopic structure and bonding, phase stability, defects, and processing history with the resultant properties and failure mechanisms of materials. Areas of application for this research include ships; ground vehicles; aircraft and missile structures; machinery and propulsion systems; microelectronic and optical components and sensors; magnetic, radar dome, and transducer materials; and advanced fiber optics for communciations.

Degradation Reactivity and Protection of Materials

This research seeks to discover the atomic, molecular, and macroscopic mechanisms that limit the durability, stability, and reliability of materials used in hostile environments and stored over long periods. The program includes studies in corrosion; oxidation; hot gas erosion; hydrogen embrittlement and hydride formation; environmental effects on polymer matrix composites; and properties of interfaces, including adhesion, thermodynamics, and kinetics of the interactions between materials and the environment. Emphasis is on novel methods for protecting materials subjected to hostile environments and complex states of stress. This research program includes: studies of self-healing coatings, ways to inhibit corrosion, computer simulation and modeling of complex interactions between materials and environment, studies of protective surface treatments, and characterization of interfaces and adhesive bonding. Studies of the phase equilibrium and microstructural features at the interfaces of thermal barrier coatings and metal substrates attempt to explain the mechanisms of protective coating adhesion at high temperatures.

Mechanical Behavior of Materials

This research addresses the relationships between the micro- and macro-structure of materials and their mechanical properties and how these relationships are influenced by environment, flaw size, loading rate, and state of stress. Major thrusts include: studies of the behavior of materials under ultrahigh rates of loading; studies in the initiation and growth of fatigue cracks; and examination of processing materials thermomechanically.

Studies of fracture will provide an understanding of the fundamental mechanisms and parameters of the materials that contribute to fracture. These studies are conducted to discover the influence that metallurgical and structural parameters have on the behavior of cracks and to develop materials with an enhanced toughness to fracturing.

Research on time-dependent mechanical behavior will provide an understanding of the mechanisms involved in fatigue, creep, and wear. Through these studies, researchers will identify the properties required for enhancing a material's resistance to deformation.

Nondestructive evaluation of materials, including developing methods for evaluating the integrity of materials, is directed toward quantitatively describing structural damage and predicting remaining life expectancy of materials. This prediction will help avoid catastrophic in-service failure of materials. The need is for new analytical concepts to detect material defects, contaminants, and microstructural characteristics that limit the performance, reliability, and reproducibility of materials. Emphasis is on quantitatively analyzing oxygen and absorbed hydrogen in polymers and polymer-based composites; predicting remaining life; detecting defects during processing; and using nondestructive evaluation to

control processing, particularly in submicron electronic materials and devices.

Synthesis and Processing of Materials

One area of DoD research that is receiving attention is superplastic forming of lower cost, lightweight structures of complex geometries. Development of a fundamental understanding of the mechanism of this process has led to an improved titanium alloy, Ti-6Al-4V-2Ni, which, compared to the conventional Ti-6Al-4V alloy (Fig. 17), has a lower superplastic forming temperature (1700 to 1500°F) and an increased room temperature yield strength (135 to 153 ksi).

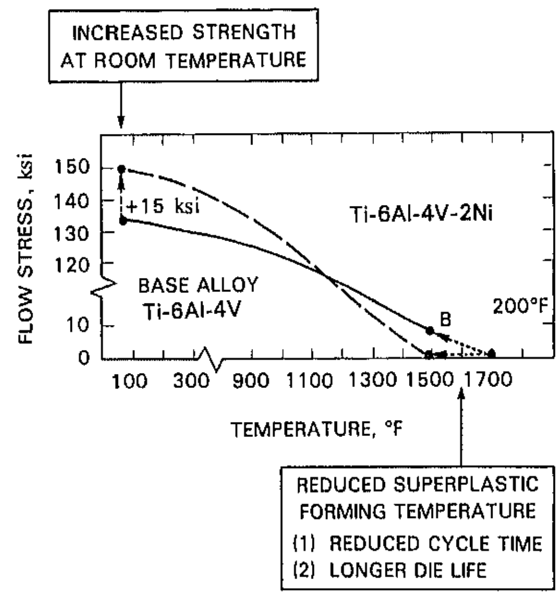


Fig. 17 — Enhanced superplasticity and strength in a titanium structural alloy

Emphasis has been placed on developing new classes of materials with improved microstructure, constitution, and properties and on advancing the understanding of how fundamental processing variables influence mechanisms of phase formation and development, microstructural evolution, and resultant properties. Trends include developing nonequilibrium materials; enhancing reliability and reducing the cost of military structures through studies in welding science and solidification; creating novel methods for processing ceramics, polymers and polymer matrix composites, and elastomers; and discovering microstructural, compositional, or other unique signatures that may be detected by nondestructive means and may serve to enhance and control the processing of materials.

Nonequilibrium Materials

The main purpose of this research is to find new materials which owe their existence to nonconventional processing methods, such as rapidly solidifying the material, making vapor-solid transitions, and implanting ions. Research topics include characterizing materials and studying: metastable microcrystalline and glassy alloys, the role of undercooling in rapid solidification rate processing, dynamic compaction of nonequilibrium (rapidly quenched) powders, laser surface alloying, ion implantation, and stability of nonequilibrium materials in severe environments.

Methods for consolidating rapidly solidified powders that retain their metastable microstructures, stoichiometry, and uniformity are especially emphasized. Single- and poly-phase ceramics and ceramic and carbon-carbon composites are under study with the goal of developing materials that are reasonably tough, lightweight, more oxidation resistant, and stronger at high temperatures than the state-of-the-art nickel-base superalloys. Such materials may also substitute for some applications that use strategic materials.

Physical Behavior of Materials

This research seeks to provide an understanding of mechanisms and key variables that determine the electronic, magnetic, and optical properties of materials; to provide new electronic, magnetic, or optical materials; and to provide techniques for processing these materials and for characterizing them on the submicrometer scale. Emphasis is on materials to be used for microelectronics (VHSIC and beyond), especially for electromigration; characterization of the microstructural and electronic nature of process-

ing defects and metallization; rare earth permanent magnets and amorphous magnets; optical materials for detectors (e.g., HgCdTe) and gradient optics; millimeter wave materials; and radiation effects on electronic and optic materials.

Magnetic Materials

This research includes investigations of permanent magnets that have high magnetic energy products (greater than 25 MGOe), the fundamental mechanisms that determine coercivity in permanent magnets, and inherent thermal compensation and stability in permanent magnets and amorphous magnets.

Microelectronics

This research includes investigations of electromigration and methods to process electronic materials, development of materials for metallization and microelectronics, studies and characterization of the atomic and electronic defects and their effects on electronic behavior, and characterization of the atomic and electronic nature of defects.

Automation Sciences

DoD is responsible for the manufacture of a variety of systems; also DoD must support and maintain these systems across a far-flung theater of operations, frequently in hostile environments, and use a largely unskilled labor force that has a high turnover rate. Although some features of the manufacture of defense hardware are the same as the mass production of other products, some unique aspects also exist. The designs of high technology weapons are typically complicated by the desire to put a great deal of capability into a small package; the desire to make the structures lightweight, which makes the package susceptible to failure from hidden flaws; and the necessity produced by cost and obsolescence to make only small production runs. To satisfy its requirements for small batches of sophisticated flaw-free components, the DoD needs manufacturing methods that are more efficient and highly automated. In the field, automated methods for isolating faults and conducting nondestructive evaluation of this hardware will become even more important. Furthermore, the DoD will require robots and automated machines to have increasingly significant roles on the battlefield itself.

Robotics

The factory of the future, capable of manufacturing small lots of highly sophisticated components, is envisaged to consist of flexible manufacturing cells or "islands," which will become the basic building blocks of a parts production and assembly facility. One component of such cells will be a very general purpose "intelligent" material handler. Today's robots are unfit for such a role; they are heavy, rigid, crude, clumsy, blind, and numb. The underlying technologies from which more sophisticated robots are expected to emerge include precise dynamic control of flexible manipulators; sensing, particularly optical and tactile sensing; intelligent systems for managing tasks by robots; and computerinterpretable, 3-dimensional vision. Fundamental contributions to these underlying technologies are expected to enable the next generation of industrial robots to be lightweight, limber, deft, facile, quick, friendly, low-powered, seeing, sensing, thinking machines that can reason and strategize (can carry out tasks on a high conceptual level).

Nondestructive Evaluation

One of the necessary subsystem cells of the automated factory will be one that handles inspection. Not only will this cell have to be able to check the dimensions of the finished part, it also must be capable of identifying hidden structural flaws and material defects that could lead to catastrophic in-service failures. The techniques used by the cell will undoubtedly incorporate some of the optical, ultrasonic, radiographic, and eddy current methods presently being refined for quantitative nondestructive evaluation of a variety of materials. Newer techniques, such as computed X-ray tomography and magnetic resonance imaging, being developed and used for medical applications may also be employed. Other techniques will be required for examination of submicron features of electronic devices. A common requirement for all techniques will be the ability of the system to identify and locate significant flaws from the response signatures of one or more interrogating signals. The use of an expert system or artificial intelligence to make such an interpretation will probably be necessary, once the quantitative flaw imaging and effect-of-defects issues have been adequately addressed.

Environmental Sciences

- **Oceanography**
- **Terrestrial Sciences**
- **Atmospheric Sciences**

Oceanography

Predictably, oceanography is of primary interest to the Navy. The objective of the research in this area is to provide knowledge of the ocean environment for the improvement of future naval systems and the most effective use of present systems.

Physical oceanography includes descriptive, analytic, and modeling studies of the open ocean environment. Emphasis is on the time variability of the ocean, with the long-term goal of developing a predictive capability for the 3-dimensional time-varying ocean structure. The scales of primary interest are those with horizontal dimensions less than 200 km and time intervals of less than 2 weeks (i.e., small and mesoscale). This focus serves Navy needs while complementing the larger scale emphases of the National Science Foundation and the National Oceanic and Atmospheric Administration. Geographic interest covers the full range of the world's oceans. Specific programs include studies of the upper ocean, including internal waves, the mixed layer, fine structure and microstructure, horizontal shear currents, atmospheric forcing and turbulence; development of new oceanographic instruments, particularly expendables, and those for use by ships of opportunity; synoptic oceanography; and remote sensing, including satellites and high-frequency over-the-horizon radars. Particular attention is given to interdisciplinary research, such as the bottom benthic boundary layer (with geology and biology), Gulf Stream rings (with biology and chemistry), the marine boundary layer (with meterology), and tomography to monitor ocean density (with acoustics).

Recently, the Mixed Layer Dynamics Experiment off the California coast visualized a long postulated phenomenon called "Langmuir Circulation." Although used for a long time to explain frequently observed ocean streaks that form at small angles to the wind, Langmuir Circulation had never actually been observed and hence could not be incorporated quantitatively in ocean mixed layer models. Figure 18 shows this circulation as manifest in the 3-dimensional velocity structure in the ocean mixed layer.

Oceanic Chemistry

The oceanic chemistry program strives to describe and understand the nature of chemical processes in the upper ocean to allow Navy personnel to predict, control, and capitalize on these processes. The three technical areas of primary concern are upper ocean chemical variability, particulate fluxes, and stability of materials. The program studies these through a combination of *in-situ* observation, often requiring the development of specialized instrumentation; laboratory experimentation under controlled conditions; and process modeling. The studies often involve interaction with the chemistry community, as well as cooperation with research in physical oceanography and the oceanic biology. A major new thrust in the program is an investigation into the marine photochemical processes that occur in the upper ocean.

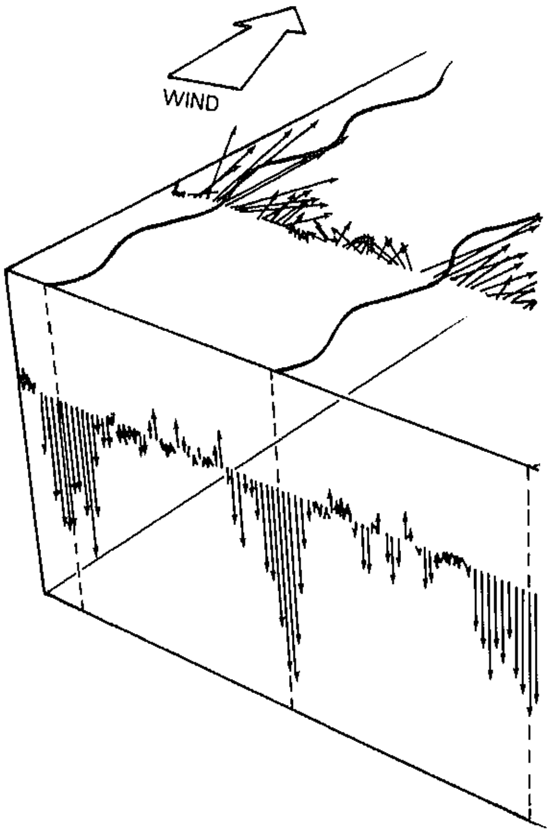


Fig. 18 — The 3-dimensional velocity structure in the ocean mixed layer (solid arrows) and the effects of the prevailing wind (broad arrows) have been observed and can be incorporated into ocean models. The solid wave-like lines show ocean surface streams, the visible manifestation of the circulation.

Marine Geology and Geophysics

In this program, the primary emphasis is to develop a detailed physical understanding of the amplitude, coherence, and mode of propagation of acoustic energy in the ocean bottom at frequencies down to about 1 Hz. Because many areas of the ocean are bottom limited (i.e., for near-surface acoustic sources, the long-range acoustic propagation paths encounter the sea floor), significant amounts of acoustic/seismic energy interact with and are propagated through the oceanic sediments, crust, and lithosphere. This interaction affects the operation of Navy surveillance systems as well as bottom-bounce sonars. The effects of bottom interaction become more apparent as frequencies become lower. At very low frequencies, it may even be possible to detect signals propagating through the ocean bottom from targets when no waterborne arrival exists. Projects are focused on determining

- the compressional velocity, shear velocity, velocity anisotropy, density structure, and attenuation of the ocean sediments, crust, and lithosphere;
- the variation of these parameters both laterally and with depth;
- the effect of the variability of these parameters on seismic propagation on the ocean bottom; and
- the interaction of the ocean bottom with acoustic energy propagating in the ocean volume.

These projects include modeling techniques, inversion studies, seismic/acoustic experiments, ambient-noise studies, and down-hole seismograph experiments in the seafloor.

Studies of benthic boundary-layer processes will provide data on the "benthic storms" that occur during the time when dynamic bottom currents exist. These currents will destroy Naval seafloor systems designed for a tranquil abyssal environment. This program will quantify the magnitude and variability of deep ocean currents; predict the response of cohesive, biological altered sediment to the imposed stresses; and examine the role of benthic boundary currents in ocean mixing of such factors as heat, salt, chemical traces, and sediment. The results will enable the prediction of seafloor physical properties and their influence on cables, structures, and potential concepts of nuclear waste disposal using the seabed.

A third program area covers the study of oceanic crustal structure, gravity field, magnetic field, and bottom bathymetry. The thrust here is

- to understand the physical processes that form the oceanic crust at ocean ridges, that

modify its characteristics with time (distance from ridge), and that cause its destruction in trench subduction zones;

- to use this background information based on plate tectonic theory to select critical areas where field experiments can test the predictability of sediment thickness, acoustic velocity structure, and crustal layering;
- to extrapolate those oceanic bottom features and properties to similar areas that are not readily accessible;
- to extend the use of marine magnetic measurements to determine the cause and effect of marine magnetic anomalies; and
- to develop and extend techniques for analyzing variation of gravity and the resulting geoid which are essential for accurate mapping of the earth, inertial navigation, improved missile targeting, undersea navigation, seamount detection, and mapping of ocean currents, fronts, and eddies.

Ocean Biology

Ocean biology encompasses all aspects of biological research in the ocean that are of concern to the Navy. This includes research in biological oceanography, i.e., the study of the oceans themselves from the standpoint of the organisms found there. An example might be the study of plankton and its interactions with the physical environment by the use of high frequency acoustics. A second type of research is marine biology: the study of the biology, physiology, and biochemistry of organisms that live in the sea. Examples might include studies of cellulose digestion in shipworms (wood boring molluscs) and in the gribble, the second major destroyer of wooden piles in piers. In both cases, this program conducts basic research to learn to break up that specific part of the biofouler's life cycle and thus allow for long-term protection of the Navy's 150 miles of wooden piers.

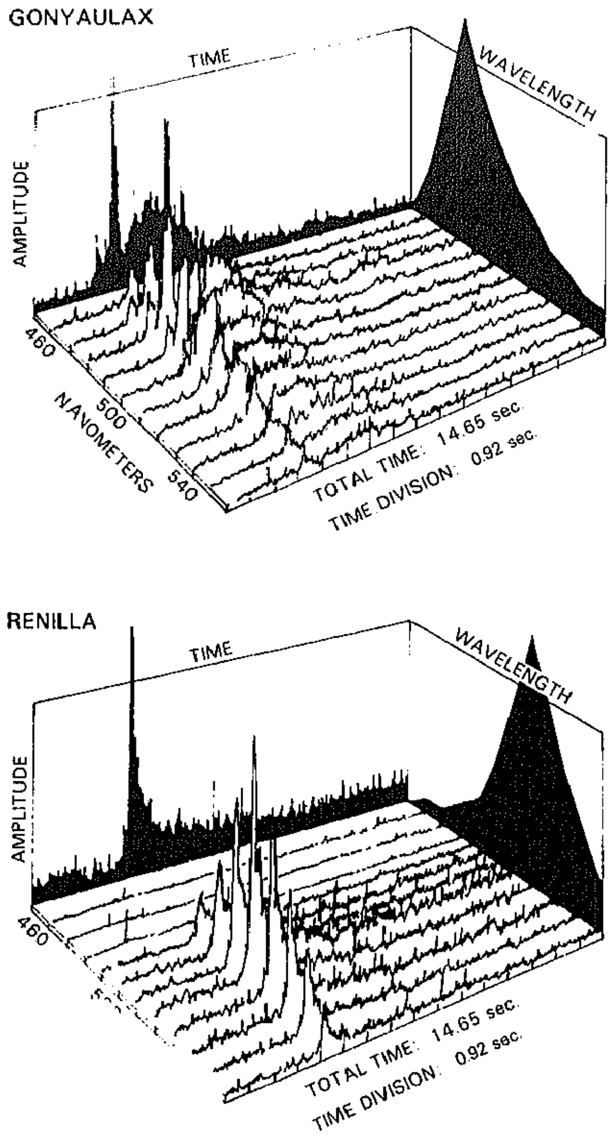
Ocean biology is subdivided into the following parts: biodeterioration, fouling, and slime films; bioacoustics, including the study of aggregations of volume-scattering organisms, and the distribution or behavior of large sound-producing animals such as cetaceans (whales and porpoises) and pinnipeds (seals and walruses); the effects of seafloor sediment/fauna interactions on the physical properties of seafloor sediments; the area, depth, and seasonal distribution of bioluminescence, as well as its temporal and spectral signature; plus small programs on noxious marine organisms (such as sharks and venomous organisms) and the perception of weak electric magnetic fields by marine species.

The temporal and/or wavelength spectra of different bioluminescent organisms in the ocean show definite differences. Figure 19 shows spectra for organisms recently observed in the ocean. Notice the broader temporal spectrum of Gonyaulax (a red tide organism) compared to Renilla (Sea Pansy). In terms of Navy significance, a knowledge of bioluminescence, in conjunction with an understanding of ocean optical properties in the surface waters, has potential applications in the areas of nonacoustic ASW and communications.

Ocean Technology

The majority of the ocean technology program is devoted to addressing basic research questions related to Navy ocean engineering. Examples of projects in this area include studies of wave and current interaction with undersea structural members, improved understanding of design environment prediction, alternative undersea search techniques based on environmental aberrations, deep underwater arc physics, benthic flame chemistry, harbor flow phenomena, and sediment particle flow interaction.

Examples of ongoing work include analyses to determine the reasons for the loss of oceanographic equipment during deep casts; development moorings for use in deep, high current environments; high data rate recorders for advanced ocean bottom seismometers; and digital data systems for use with towed oceanographic systems.



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Ocean Acoustics

The ocean acoustics program is directed toward determining the fundamental constraints which the ocean environment places on the use of underwater acoustics by the Navy. Recently,

increased emphasis has been placed on bottom acoustics because the bottom becomes increasingly important at lower frequencies. Theoretical emphasis is on lateral variability and anisotrophy in bottom-propagation models. In the area of random wave propagation, greatest emphasis has been on the clarification of the influence of internal waves and fine structure on sound transmission. Acoustic tomographic experiments are under way to develop ocean-basin mapping techniques to define and track ocean fronts and eddies. Here, the acoustic inversion problem in producing synoptic, real-time sound velocity profiles is particularly difficult. Surface acoustics is concerned with achieving a detailed physical understanding of how sound interacts with a rough surface that is not easily characterizable in a theoretical sense.

Research Vessels

Twenty percent of oceanography funding is devoted to research-vessel operations for at-sea experiments, or to programs for upgrading research-vessel equipment. These are primarily Navy-owned vessels operated by academic oceanographic institutions. The equipment-upgrade program to enhance the effectiveness of these research vessels encompasses two areas: mid-life replacement of hull equipment (such as AC generators, bow thrusters, and oceanographic winches) and installation of new scientific equipment to increase the scientific productivity of the research vessels and to open new fields of ocean research to the academic community. Five examples: multibeam echo sounders will be installed on at least two of the research vessels. These will provide a geomorphic picture of the seafloor instead of the single-tract data currently available. Doppler velocity measurements of upper ocean currents, combined with precise Global Position System navigation data, will provide a new picture of the upper ocean dynamics, particularly near oceanfronts. Long towed seismic arrays will facilitate studies of sediment, crust, mantle layering, and heterogeneity. New acoustic and TV sensors will define the precise distribution of plankton, rather than the previous smeared picture provided by net tows. Towed chemical pumping systems and, eventually, *in situ* sensors will provide new concepts in the distribution of ocean trace elements, reduced gases, and dissolved organic matter.

Terrestrial Sciences

Research in the terrestrial sciences spans a spectrum from small-scale Earth motions to spectral signatures of backgrounds at many wavelengths. Predicting the effects of dynamic processes operating at and near Earth's surface is the ultimate objective of terrestrial sciences research. Requirements for such knowledge stem from the obvious needs of increasingly mobile and flexible combat operations and the ensuing near real-time necessity for environmental information. There are also the needs of military construction, a necessity for understanding and mitigating environmental degradation at military training facilities. With few exceptions, terrestrial sciences research within DoD operates the mainstream of fundamental research in the Earth sciences. Civilian spin offs of such research are many, including earthquake prediction, construction techniques on permafrost, dredged material disposal, and navigation improvement.

Properties of Earth Materials

Applications continually challenge our understanding of the physical, mechanical, and electromagnetic properties of soils, rocks, and such transient materials as snow and ice. Topics of particular interest include stress and shock wave propagation through cohesive and non-cohesive (granular) soils, relationships between *in-situ* measured properties and laboratory measurements and the dielectric and scattering properties of soils and snow at various electromagnetic wavelengths. The fundamental physics of electromagnetic propagation and scattering in snow on the ground is poorly understood. Results from millimeter wavelength experiments have been modeled in terms of nonphysical parameters leading to gross uncertainties in the extrapolation to shorter wavelength systems. The effectiveness of an explosive in a snow cover can be affected by a number of factors, one of which is the free water content. Research has shown that wet snow does attenuate the pressure wave more rapidly than dry snow, and that in the case of wet snow, the rate of attenuation increases with free water content. The military implications of this research are obvious, but the civilian spin off in areas of avalanche release are also important.

Geodesy and Gravity

Within the area of geodesy and gravity, research is conducted on the fundamental Earth properties to derive geodetic and astronomic positions, to determine and improve the shape of the geoid, and to model the acceleration of gravity. Improved instrumentation is developed to measure various geodetic parameters with increased precision. Interferometric techniques are being investigated which could greatly improve measuring geodetic baselines. Studies continue to obtain information about the small-scale variations of the geoid using analyses of satellite orbits. These programs are directed toward meeting the goals of the geodetic and gravimetric contributions to future ICBM and cruise missile error budgets.

Earth Motions

The goal of the research conducted within Earth motions is to measure and characterize the effects of motions, both natural, cultural, and those due to nuclear detonation, on various systems, e.g., missiles and launch vehicles. Models of ground motions, the result of nuclear detonations, are based on measurements of the propagation of seismic waves associated with earthquakes and controlled detonation of chemical explosives. Analytic, laboratory, and empirical models will be compared to verify predictions of ground motions at likely advanced ICBM basing sites. The experience gained from modeling seismic propagation in complex terrain is being included in missile launch predictions.

Earth-Fluid Dynamic Processes

The interaction of water and wind with Earth materials is a dynamic, continuing process

that initiates a variety of phenomena intrinsically interesting, but of critical importance to the military. Research is supported in such areas as

- flood prediction in small ungaged stream basins,
- mechanisms of dust generation and susceptibility as a function of soil type,
- enhanced erosion potential due to off-road vehicular traffic, and
- coastal zone dynamics.

Recent studies supported by DoD have shown that within a WWII base camp in the Mojave Desert accelerated erosion is taking place as a result of soil and vegetation alterations. The number of incised runoff channels in disturbed areas is 100% greater than in control plots in the same drainage basin. Understanding the susceptability of soils and vegetation to disturbance will enable better land management on military bases.

Geophysical Remote Sensing and Mapping

Novel concepts are explored for measuring and interpreting surface and subsurface properties and anomalies on land and in Arctic and coastal regions, geodetic modeling, location of submerged navigational hazards, terrain modeling, sensor modeling, feature signatures and location, as well as image (and other) sensor interpretation and processing for automated mapping processes. Various applications on seismic sensors are important for remote battlefield and shallow water surveillance and intelligence gathering (including nuclear test detection), as well as for estimating earthquake risk at military installation sites. Applications of new technology in cryogenic instruments for surveillance and improved geophysical surveying are important for detection of weapons systems. New techniques are explored in geophysical signal processing and inverse problems.

Geomagnetic and Electromagnetic Field Variability

The study of external and induced geomagnetic and electromagnetic fields and their variability are important for temporal and spatial prediction in magnetic anomaly detection operations, mine warfare, shallow water surveillance, and passive geophysical navigation. Modeling and field studies on the effect of rock electrical conductivity on the induced geomagnetic field and on the spectra of environmental electromagnetic ambient noise are also of interest.

Atmospheric Sciences

The atmosphere has powerfully influenced military operations and the use of weapons. For example, the harsh Soviet winter thwarted Napoleon's Russian campaign. Conversely, the forecasted break in weather over Normandy was crucial to the Allies' decision on D day in World War II. As today's operations and weapons become more sophisticated and computerized, the increased likelihood that the weapons will be delivered accurately is somewhat offset by their increased sensitivity to previously unimportant atmospheric conditions, such as clouds, haze, and smoke. When the atmosphere is such that "seeing" through it is more difficult or impossible (that is, microwaves and visible, ultraviolet, and infrared light cannot be transmitted through it), then problems appear in accurately navigating missiles, in predicting aircraft launch conditions and land and sea conditions, and in identifying and acquiring targets. The decisions made about the "seeing" conditions are affected by the changing concentrations of the atmospheric gases (water vapor and ozone), and particulates (dust, haze, precipitation) varying refractive conditions; and fluctuating radiation backgrounds, such as those found in the aurora. Increasing the probability of military success and minimizing problems depends in part on continuing to emphasize research in atmospheric sciences.

Cloud and Aerosol Physics

This research is concerned with characterizing natural and synthetic solid and liquid particles in the atmosphere; describing the physical, chemical, and electrical processes that result in the growth, size spectrum variations (number of particles of each size), number density changes (number of particles in a given volume), and dissipation of natural aerosols (rain out, chemical action, etc.); developing instrumentation techniques; and creating usable models for predicting and specifying atmospheric conditions.

Atmospheric Effects on Transmission

The study of atmospheric effects on transmission entails actively and passively measuring the following properties and constituents of the atmosphere (for ultraviolet through millimeter wavelengths): shapes of spectral lines; line broadening effects (such as those due to pressure); dependence on atmospheric temperature; absorption by the atmosphere; scattering and refractive indices; effects of turbulence on electromagnetic propagation; transmission of energy through clouds; and cloud reflectance. Modeling these properties for their effect on atmospheric transmission phenomena is also required. This kind of research is most necessary to improve performance of weapons, which depend on electro-optic and millimeter wave guidance and target-seeking systems. All aspects of this topic continue to be important.

Small-Scale Atmospheric Processes

Studies of small-scale atmospheric processes include: predictions of micro- and meso-scale flow (scale sizes: 1 km to several tens of kilometers), the effects of topography, local heating, and friction; models of temporal and spatial variability over time scales of minutes to hours and spatial scales of meters to tens of kilometers horizontally and 5 kilometers vertically; models for studying atmospheric transport mechanisms of natural and artificial materials that have been released into the atmosphere; and models of clouds. Interactive dynamics of individual clouds are also of interest for modeling regional dynamic systems (e.g., clusters of thunderstorms). These phenomena affect aircraft and helicopter operations that are near the ground and at high altitudes. They represent an area of continued study.

Middle Atmospheric Processes

The middle atmosphere typically extends from 10 kilometers to 95 kilometers above the earth's surface. Studies of the processes that

occur in the middle atmosphere include the following: diurnal, seasonal, and spatial variations of atmospheric constituents at the atomic, molecular, and particulate level; atmospheric dynamics, including diffusion, wind and waves, heave, and striations; the interaction of radiation with the atmosphere; electrical phenomena in the atmosphere; coupling of upper and lower atmosphere through the middle atmosphere. New methods of sensing the middle atmosphere offer great opportunity for new technology important to the success of surveillance systems.

Measurements of Solar Transmission

Satellite techniques are used to look at the solar transmission at satellite sunset and sunrise. Researchers can then determine very high altitude refraction and more precisely locate stars, which are used to correct the midcourse navigation of large weapons. This technique is also used for gathering information about the constituents and properties of the atmosphere. Opportunities continue in the area of Earth-limb sensing technology.

Longer Range and More Accurate Forecasts

Climate dynamics, solar-terrestrial connections, the coupling of upper and lower atmospheric dynamics, and the cooling of tropical latitude circulations are studied to help improve and extend the usable lead time of numerical weather prediction. Other studies focus on planetary boundary layer effects, such as the effect of the mountains on weather; effects of atmospheric moisture; and processes for transporting energy through the atmosphere.

Atmospheric Radiative Processes

The study of atmospheric radiative processes includes measuring and modeling the mechanisms behind the processes in the upper atmosphere that control infrared and optical emissions in auroral and nuclear-disturbed atmospheres; determining spectral, spatial, and temporal variability of airglow emissions with and without solar illumination; and measuring excited-state emissions that result from the interaction between high velocity rocket plumes and the atmosphere. These measurements are necessary to assess and evaluate the feasibility and effectiveness of various through-the-atmosphere optical and infrared DoD sensors used for detection, surveillance, communications, and target identification. Continuing opportunities abound for research in this area.

Upper Atmospheric and Ionospheric Composition and Structure

This research includes studies of the upper atmosphere that measure chemical constituents (such as nitrogen compounds); identify new, probable, suspected, or unsuspected chemical species in the chemical structure of the upper atmosphere; measure and model ionospheric structure and behavior, especially with respect to the dynamics and dynamic influences on the compositional structure of the ionosphere; measure and model density structure of the ionosphere and scintillation phenomena (such as airglow). These studies are most important for understanding the effects of the upper atmosphere and ionosphere on DoD communications, surveillance and warning systems, and the development of new capabilities in space systems.

Marine Boundary Layer

This research involves the study and the modeling of the interactions between the air and the sea, particularly the micro- and meso-scale transfer of momentum, heat, and moisture. Aerosol distribution, fog formation, visibility, and other factors that affect the formation and maintenance of the marine boundary layer structure are also of interest. They are important to understand synoptic and storm situations, such as weather patterns over oceans.

Life Sciences

- **Biological and Medical Sciences**
- **Behavioral Sciences**

Biological and Medical Sciences

Research in biological and medical sciences supports DoD's efforts to protect and conserve its most valuable resource, human beings, and to capitalize on biological processes and materials with potential military applications. The prevention and treatment of militarily significant diseases and the care of combat wounded are classical concerns of this area; these concerns are compounded by the emergence of new disease threats in strategically important areas of the world and the ability of enemy threat systems to produce a variety and severity of combat injury unseen in former conflicts. The physiological demands imposed by modern weapon systems and doctrine are also of concern. These demands approach and may exceed the limits of human tolerance, thus making people the limiting factor in modern systems design.

Human Hazard Protection and Performance

Modern combat doctrine and weapons systems make heavy demands upon military personnel. Research in this area aims to provide the human biological data bases needed to protect and support human beings in combat.

The major goal of interest in this area is the determination of the biological effects and human tolerance of such military environmental stresses as nonionizing radiation, toxic emissions of weapons systems, physical force environments (vibration, impact, and acceleration), and environmental extremes (heat, cold, high altitude, and deep submergence). Knowledge of the distribution and absorption of electromagnetic energy at tissue and cellular levels is necessary to determine safe exposure levels, both for regulatory purposes and to ensure optimal human performance in the presence of such radiation. This is particularly critical given the development and proliferation of pulsed and high-frequency (millimeter and near-millimeter) systems, which may in some circumstances produce nonthermal effects in certain biological tissues. Such effects have been reported by Eastern bloc researchers, though not uniformly reproduced in our own laboratories. Investigations into the biological effects of physical and environmental stress are needed to provide design criteria for safer, more effective military systems. Such research extends the concern with the man-machine interface beyond static anthropometry to the physiology of perception and performance, and to the dynamics (both physical and psychological) of the interaction of the operator and the developmental system.

Doctrinal concepts also place great demands upon human physical and neurophysiological capabilities. Studies of physical and mental fitness, nutrition, and unit effectiveness seek to avoid or overcome the effects of fatigue, isolation, rapid translocation, and continuous performance—demands imposed by modern combat.

Another vital interest is the defense of the individual against chemical and biological (CB) weapons. These investigations deal with detection of CB agents, decontamination of exposed personnel and material, and treatment of exposed personnel. This last topic requires an understanding of how the CB agent acts against the body. A typical nerve gas agent is an anticholinesterase

which inhibits the breakdown of the nerve impulse transmitter acetylcholine. More research needs to be done to more fully understand the action of this and other transmitters. A related topic of interest is innovative materials for human protective clothing and equipment.

Food and Nutrition Sciences

The DoD has a continuing interest in better ways to preserve, protect, and deliver food to the combat field to include extension of ration shelf life, reduction of weight and bulk, and protection of food from natural contamination and pests. Future interest areas will include determination of possible interactions between foods consumed and physical and mental performance. Such studies will involve collateral investigation of human food behavior/acceptance under combat stress conditions.

Infectious Disease

Major topics in this area include the epidemiology, microbiology, immunology, and pathophysiology of infectious diseases of known or possible military significance. The list of diseases of concern is long and worldwide in scope. We are primarily concerned with understanding tropical diseases, potential biological agents, and diseases which hamper mobilization and deployment. Knowledge of the interactions among the human host, the infecting agent, and vectors (if any) are essential for the development of control and avoidance techniques. Entomological studies of disease vectors are also important. Pharmacological studies are undertaken to help in producing safe and effective curative and therapeutic drugs.

Diseases of major concern in this area are malaria, dengue, plague, scrub typhus, leishmaniasis, hepatitis, Rift Valley fever, Ebola/Marburg, Lassa fever, diarrheal disease, respiratory disease, schistosomiasis, and arbovirus infections. A promising vaccine against malaria is near testing.

New techniques emerging from basic research in biology and medicine will be increasingly exploited to advance knowledge in this area. Recombinant DNA methodology provides a basis for improved strain definition and production of immunological reagents, as do monoclonal antibody techniques. The ability to cultivate fastidious organisms *in vitro* (as with malaria) will substantially advance abilities for field and laboratory assessment of infectious diseases. Knowledge of host pathogen relationships in viral infection will hasten development of antiviral compounds. There is need to exploit these newer scientific tools to address military infectious disease problems. Rational approaches to drug synthesis have revolutionized antimalarial therapeutic pharmacology; these concepts need to be extended to other diseases of interest to the military.

Improved knowledge of the epidemiology and geographic distribution of infectious disease is of special military concern. Future programmatic and operational decision making will depend on this data base.

Combat Casualty Care

Combat trauma is of particular concern to the military. In addition to typical interest in the pathophysiology of injury, and exploration of new bases for surgical and ancillary care, there is increased interest in the epidemiology of wounding and the physiology of wound healing. Implicit is a need for more complete understanding of relevant normal human physiology.

A fuller understanding, for example, of neurophysiology, in addition to providing a firmer basis for defense against chemical warfare agents, is needed for better, more definitive early field care of specific types of injury.

Improved diagnosis of injury, anesthesia, and the basis of traumatic shock are other topics of interest in this area. Much recent interest centers on the possible role of endorphins in ameliorating pain and shock.

Red blood cells, highly effective carriers of essential oxygen to tissues, are needed in large quantities to treat blood loss casualties. Navy

researchers have devised ways of freezing red cells for long-term storage. However, these methods cannot meet the demand for blood in time of war or other disasters. One approach (Fig. 20) that will double the available blood supply is to convert Types A and B blood cells (50% of American donors) to the Universal Donor Type, Type O. Type O cells lack sugar molecules on their surface that define Types A and B, and can be injected into any recipient. When available, Type O cells do away with the need for typing the recipient prior to transfusion, saving time on the battlefield or in the emergency room. Because the sugars that define Types A and B cells are fairly unique biochemically, they can be removed from the red cells surface by certain enzymes without disturbing essential surface sugars. The research isolated a suitable enzyme for removing the B sugar, and researchers are now finishing work on enzymes that remove the A sugar. Work with the B enzyme has shown that the approach is feasible and safe for humans.

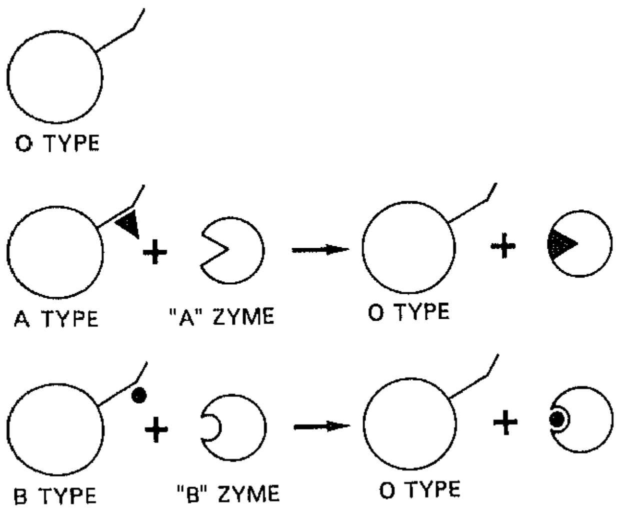

Fig. 20 – Conversion of Types A and B blood cells to the universal blood donor type, Type O, is being pursued by using certain enzymes to remove the sugars that define Type A and B cells

Historically, much of the effort in this area has aimed at improvements in hospital-based care. New directions are emerging toward development of knowledge needed for early care of the wounded, for care rendered in remote areas without highly skilled personnel, and for improvements in the efficiency of medical care systems, both field and fixed.

Biology

A relatively small effort is devoted to the avoidance of economic loss due to the action of biological organisms on military material. Integrated pest management approaches the problem of insect infestation of stored foodstuffs is one example. Other interests include fungi which cause deterioration in textiles and other materials.

To take full advantage of the strong technological potential inherent in biomolecular engineering, it is necessary to further our understanding in a number of areas of basic research relevant to the structure and activity of various macromolecules. Of great importance is the need to expand research in the fields dealing with the nature of protein-nucleic acid interactions, structure-function relationships in these and other macromolecules, characteristics of enzyme and membrane receptor active sites and their relation to peripheral site influence, and gene expression and its regulation in microbial, plant, and animal cells.

One long-range goal of protein engineering research is the design and synthesis of novel and altered polypeptides to provide efficient catalysts and specific binding proteins not readily available in nature. One approach is the preparation of novel polypeptides using solid phase organic synthesis to make model catalysts and analyze their structural properties by X-ray diffraction. Another approach involves genetic engineering to generate mutant or altered protein molecules. Work on the membrane associated light absorbing proteins (opsins) from bacterial and mammalian systems is one example.

Rhodopsin is the main visual pigment in both vertebrates and invertebrates. Similarly, bacteriorhodopsin catalyzes light-driven proton translocation across the purple membrane in several halophilic bacteria. The resulting electrochemical gradient can be exploited by the cell for

useful work. In both systems, retinal is the light-absorbing pigment. The pigment is linked to the protein opsin *via* a lysine residue. The isomerization of retinal from the cis to the trans configuration is the initial step in photon capture and light transduction (Fig. 21). The structure of the opsin molecule affects the wavelength of light absorbed by the retinal (to which it is attached). Thus, the light absorbing system is an excellent model for studying structure-function relationships in polypeptides.

Recently, the bacteriorhodopsin molecule was purified and sequenced. This led to the development of an *in vitro* reconstitution system to study the function of the purified protein at the molecular level. The gene coding for bacteriorhodopsin has also been cloned and expressed. Thus, the bacteriorhodopsin molecule can now be manipulated structurally using genetic engineering. The effects of these alterations on the protein's function can be observed using the *in vitro* reconstitution system. Using a photosensitive retinal analog, the amino acids in rhodopsin that are oriented in close proximity to the retinal cofactor have been identified. The continuing research is now generating bacteriorhodopsin molecules with alterations of these amino acids to determine the structural requisites associated with the light-transducing function of the molecule.

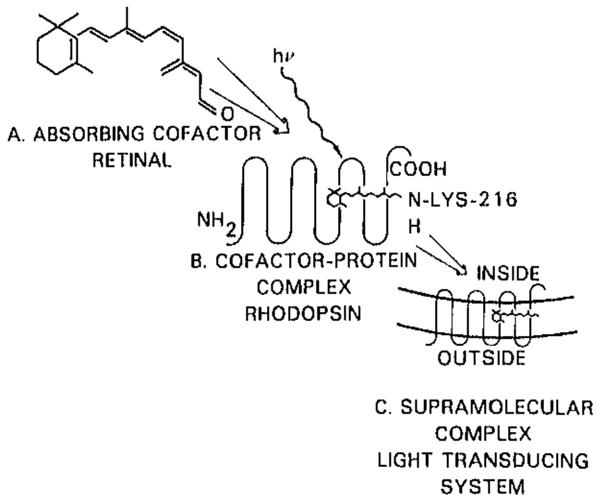

Fig. 21 — In living organisms light is absorbed and transduced by a highly organized complex of molecules. The absorbing chromophore is the low molecular weight cofactor, retinal (A). The wavelength of light monitored by a particular system is modulated by the microenvironment of retinal which is a function of the amino acid composition of the rhodopsin protein (B). The exact 3-dimension structure of the rhodopsin-retinal complex is maintained by its orientation in a cellular membrane (C).

Behavioral Sciences

The goal of research in the behavioral sciences is to increase understanding of human performance under conditions that are typical in a military environment. This environment is becoming increasingly complex due to more sophisticated weapon systems and heightened tempo of battle, which place mounting operational and personal demands on individuals and groups. Even the pressures of changing priorities in our social system during peacetime are sensed by military personnel. DoD supports research that lays the foundation for understanding and enhancing performance of military personnel in training settings, during operation and maintenance of systems, and as team members.

Sensory, Perceptual, and Motor Processes

Advances in quantitative descriptions and models of human vision, audition, pattern recognition, haptics, and motor control are increasingly important. Information processing models of visual perception; auditory perception of complex, nonspeech sounds; and tactile pattern recognition are of particular interest. DoD encourages interdisciplinary research which includes investigations at both the behavioral and neural levels. Results of this research form a foundation for the design of more effective visual displays, including computer-generated imagery, design of auditory systems, and remote manipulation systems.

Cognition and Decision Making

Research to understand and model complex cognitive and decision behavior focuses on processes and structures underlying skilled performance in real-world tasks such as planning, problem solving, understanding technical information, situation assessment from incomplete information, and choice behavior under conditions of uncertainty and risk. Differences in the mental models and ways of representing knowledge that are typical of different stages of developing expertise are of interest. Common biases in decision making, and mechanisms explaining these biases, are quantified and modeled. New thrusts are concerned with group decision making, especially in groups whose members are physically dispersed. Results of this research provide a basis for development of artificially intelligent "expert" tutors, decision aids, and unburdening techniques in command and control systems.

Instructional Theory and Advanced Instructional Systems

Training in the military is a large-scale and expensive operation in which substantial payoffs accrue from increased effectiveness or reduced costs. Research seeks to understand better the learning process and to investigate new technological opportunities which might facilitate learning. New theories are sought to describe and explain the learning of basic skills such as reading, arithmetic and spatial relations, more technical skills such as equipment maintenance, troubleshooting and computer programming, and tactical skills such as planning, decision making, flight control, air control, and navigation. Theoretical approaches are investigated, such as the analysis of complex skills into more elementary components which represent relatively independent skill areas, or differences between ability to acquire a knowledge base of information as compared with a knowledge of procedures or strategies in handling that information. The most appropriate roles of computer-based instructional techniques and, more recently, of intelligent computer-assisted instruction are of particular interest.

Theoretical Models of Human-Computer Interaction

Current interest in man-machine interaction emphasizes the theoretical understanding of

humans performing as either computer operators or programmers. Computerized systems are now being applied to improve performance in a wide variety of jobs. But to realize these advantages, such systems must be designed to be compatible with fundamental human performance capabilities and limitations. Generic models of these performance characteristics are sought, to provide a basis for development of design principles for computer programming procedures, maintenance of data bases, and effective operator-computer interaction. A better understanding of human interaction with intelligent systems is also sought.

Theory-Based Personnel Measurement

Effective design of personnel tests depends upon the ability to make reasonably valid and reliable estimates of two variables that are initially unknown: the diagnostic ability of each test item to distinguish the degrees of ability, and the actual distribution of a statistical population along the ability scale of the inferred trait.

Theory-based personnel measurement, which includes item response theory or latent trait theory, seeks efficient techniques to estimate both of those variables from samples of test item responses. Advances in this field are dependent on the development of more powerful statistical and numerical tools for handling psychometric data, and on conceptual models of ability distributions that permit use of these tools with as few constraining assumptions as possible. Results of this research enable test developers to calibrate test items along ability scales, including scales of multiple traits; they make possible the generation of test items that more precisely diagnose skill deficiencies; and they permit the development of computer-based adaptive tests that have several important advantages over traditional paper-and-pencil tests.

Group Psychology

Research in this area seeks new theories and more precise predictive models of various factors that affect the productivity and commitment of teams and groups. There is interest in understanding the impact of individuals with different characteristics on team performance, as well as the processes that occur when individuals influence groups and when groups influence individuals. Group information processing, structure, incentives, and team training regimens are factors of concern. Development of significant measures of team performance, including group decision effectiveness, coordinated activity, and resistance to personnel turnover, are also of interest. There are particular needs for research on hierarchically organized groups and on the effects of stress on group/team performance.

DoD Departments/Agency

- **Department of the Army**
- **Department of the Navy**
- **Department of the Air Force**
- **Defense Advanced Research Projects Agency**

Department of the Army

The Army's basic research program is divided into two distinct segments: the in-house work, performed in the Army's 35 laboratories, and the extramural effort. Figure 22 shows the many organizations involved in research efforts and how they relate to the command chain. The Army's research program is either conducted in-house or contracted-out to the laboratories associated with the Army Materiel Command (AMC). AMC is responsible for the development and acquisition of all the Army's combat and combat support systems. Within AMC, the Army Research Office (ARO) provides the principal interface with universities. With such a broad mission, AMC performs most of the Army's research program (70% for FY 1984). The remainder of the program is divided among the Surgeon General's Office and the Medical R&D Command (24%), the Corps of Engineers (4%), and the Army Research Institute for the Behavioral and Social Sciences (2%), which reports to the Deputy Chief of Staff for Personnel.

Extramural Program

Along with the contracts let by in-house laboratories in support of their own programs, much of the extramural research program is in the form of contracts from ARO, mainly to academia, with a small number going to industry and nonprofit organizations. There is also an overseas contract program carried out by the European Research Office which receives funds and program guidance from ARO. ARO's program is structured along lines similar to the DoD disciplines, which have been discussed in the first half of the report, with a division director and staff in each of the following areas:

Atmospheric and terrestial sciences
Biological sciences
Chemistry
Communication engineering
  and electronics
Materials
Mathematics
Mechanics and aeronautics
Physics

The ARO program is a mix of short-, mid-, and long-term programs that are responsive to the needs of the Army laboratories. The programs reflect the judgment of the ARO staff of what is new and exciting. Higher-risk work may have large payoffs in the future. Since the implementation of the Competition in Contracting Act on April 1, 1985, ARO has published a broad agency announcement which outlines the specific research areas of interest and the procedure for submitting a research proposal. All proposals falling within the guidelines of that broad agency announcement are considered competitive. In recent years, ARO has agressively sought direct interactions with the Army Training and Doctrine Command and its schools to assist in shaping the ARO program according to Army mission area needs. An example of this is the increased

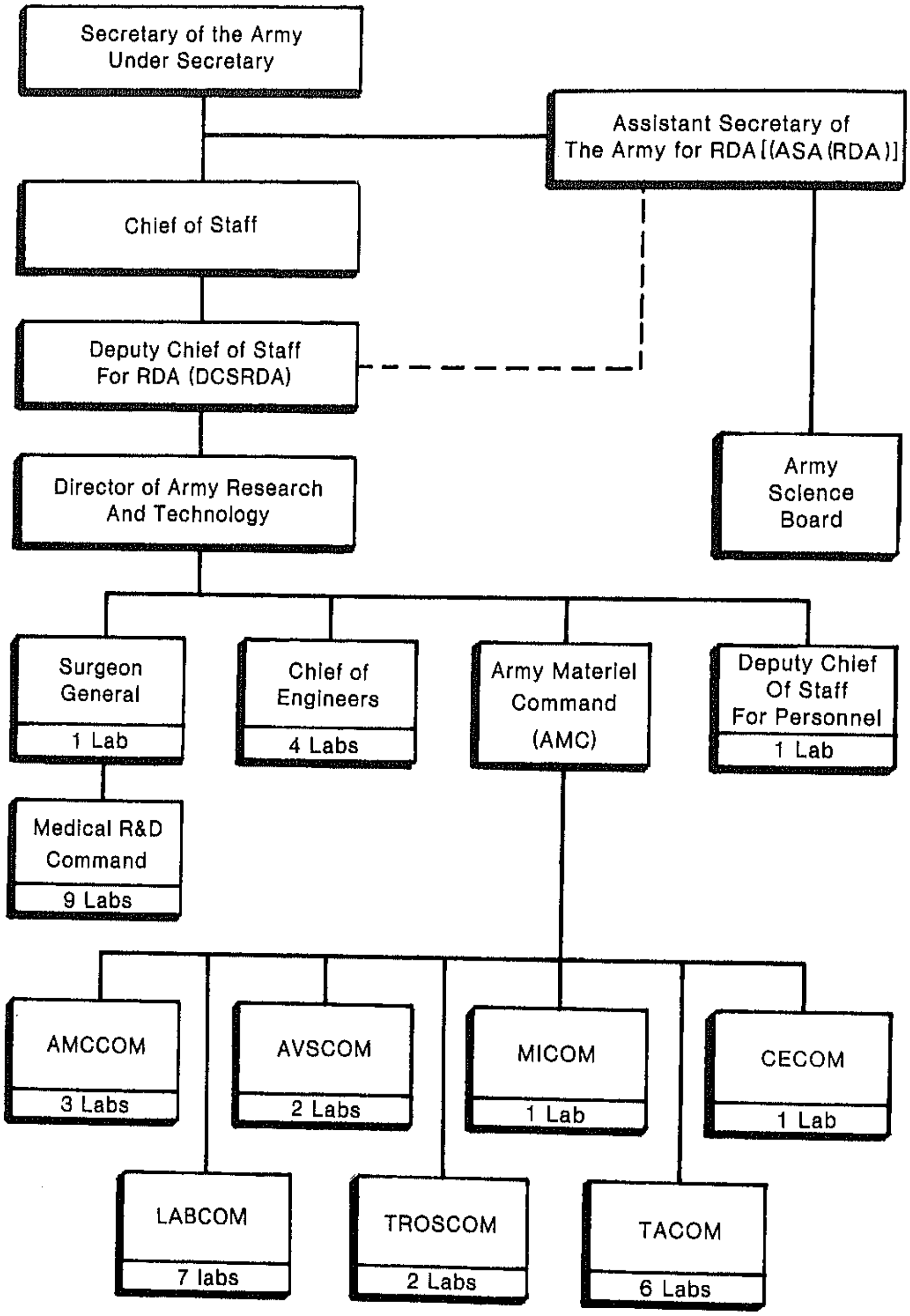

Fig. 22 — Army research management structure

emphasis placed by several of its divisions on various aspects of chemical and biological warfare defense research which results from very intensive joint planning in this area among ARO, the Chemical Research and Development Center, and the U.S. Army Chemical Schools.

When proposals are received, ARO subjects them to a three-level review: a peer review in the scientific community for technical excellence, an Army laboratory review for both excellence and military relevance, and an ARO internal review. The funding of the proposals depends on the results of these reviews. Through the Scientific Liaison Program, individuals in the army labs may request to be kept apprised of specific programs and to receive copies of reports and publications that may prove to be useful to their own projects. Once a year, the entire ARO program is evaluated by the AMC Laboratory Directors to determine how it fulfills the needs of their own organizations. Contracts with the 35 in-house laboratories are negotiated directly with the in-house laboratory researchers.

In-House Program

The in-house laboratories' program is organized along the lines of the laboratories responsibilities. Each laboratory's research effort is supported by a Single Project Funded (SPF) line item which relates more closely to the overall mission of the lab than to some specific scientific discipline. The content of each SPF is determined by each laboratory's Technical Director and his staff. Research in the laboratories is designed to be the first step in the development chain; many of the tasks undertaken within the SPF are intended to eventually lead into development programs. The technical content of the SPF's is formally reviewed annually by each Command Headquarters and by the Directorate of Army Research and Technology. This evaluation process provides an opportunity for closer coupling of the Army's in-house and extramural programs.

From time to time, the Assistant Secretary of the Army for Research, Development, and Acquisition will also request the Army Science Board (ASB) to review some particular area of the research program to assure its responsiveness to some especially pressing Army problem.

Technology Areas Of Emphasis

Besides the laboratories' mission-oriented research program and ARO's discipline-oriented program, the Director of Army Research and Technology (DART) has also identified technology thrusts. These are areas that respond to specific military needs, have a high urgency, and might be solved by a major infusion of technological effort. Research in these areas is encouraged and is given preference in the annual budget cycle. The related tasks are usually performed by several laboratories in-house and on contract within their respective SPF's, and the work is coordinated either formally through some form of planning document or informally through oversight by each Command Headquarters and the Department of the Army Headquarter's Office of the Director of Army Research.

Although all of the Army's research concerns are not addressed, efforts in such all-important areas as mobility, survivability, and firepower will certainly continue. We have, however, designed thrusts to avail ourselves of the advantage to be gained from some of our genuinely high leverage technologies.

Research efforts support thrusts in a number of areas, including very intelligent surveillance and target acquisition (VISTA); distributed command, control, communications, and intelligence (C^3I); self-contained munitions; biotechnology; and the soldier-machine interface.

Case History in Army R&D Management

In the spring of 1980, a panel commissioned by the Assistant Secretary of the Army for RD&A conducted a vertical lift technology review and recommended the establishment of a small number of Centers of Excellence in Rotary Wing Aircraft Technology among respected U.S. universities and colleges. With this mandate, the

necessary funding was made available in FY 1982 to initiate three Centers of Excellence. After an intensive competition, centers were established at the Georgia Institute of Technology, at the Rensselaer Polytechnic Institute, and at the University of Maryland. The total fiscal outlay for the program during a 5-year period is a little over $13 million.

The objectives of these schools are to establish in-depth and fundamental research programs, update and develop the necessary equipment and facilities for supporting the expanded research, and to establish the related curricula for advanced degrees in rotary wing aircraft technology. This program, that is now under way, consequently will provide the entire helicopter industry with an additional technology-base for the advancement of the state-of-the-art in this important field.

Of special significance for the management of the Army's program in rotorcraft technology are the review and advisory panels that have been created. An evaluation panel has been established to review the programs in each Center, at ARO, and at the Army Aviation Systems Command's (AVSCOM) laboratories. Moreover, each Center has an Advisory Board made up of senior technical executives from the helicopter industry, National Aeronautics and Space Administration (NASA), and the Army Aviation Systems Command. These working relationships and the close coordination of the research programs in the Centers, at ARO, and in the AVSCOM laboratories have provided a beneficial stimulation and synergism to helicopter research and a continual updated awareness in NASA and in industry of the Army's needs in rotorcraft technology.

Department of the Navy

The Office of Naval Research (ONR), under the direction of the Chief of Naval Research, reports directly to the Assistant Secretary of the Navy for Research, Engineering and Systems. ONR was established by an Act of Congress in 1946 (Public Law 588, 79th Congress), which granted the new organization the statutory responsibility "to plan, foster and encourage scientific research in support of its paramount importance and maintenance of future naval power for the preservation of national security." The Navy has an enduring requirement for research to establish the scientific foundation of understanding, techniques, and information necessary for its future systems and operations.

ONR's organizational structure, under the Navy Secretariat (Fig. 23), ensures that research funds remain properly insulated, but not isolated, from the pressure of resource requirements in the Navy's near-term development programs. An awareness of development and of fleet problems, which frequently indicate the necessity for research investment, is maintained through close and continuous interaction with the Office of the Chief of Naval Operations (OPNAV), the Naval Material Command (NAVMAT), and its laboratories. ONR is also responsible for fulfilling the requirements for research of the Marine Corps.

Extramural Program

ONR supports two major types of programs. First, fundamental knowledge that leads to solutions of Navy problems is acquired through support of long-range research. Second, programs of applied research and exploratory development are conducted to develop naval technologies and to study and test new concepts in naval operational systems. The scientific directorates in support of these research and development programs are:

Mathematical and Physical Sciences
Environmental Sciences
Engineering Sciences
Life Sciences

Generally, contracts are awarded in response to unsolicited proposals. The academic, in-house laboratory, and acquisition manager constituencies are frequently consulted for opinions on individual proposals. The criteria employed in evaluating specific proposals are:

- excellence and creativity of the principal investigator, as evidenced by previous publications and reputation within the scientific community,
- relationship to Navy and Marine Corps needs,
- correspondence to previously stated program thrusts, and
- evidence of uniqueness and appreciation for other similar efforts being funded by other government agencies in the field.

The selection of major thrusts evolves mostly from relevance and opportunity, while decisions on individual program proposals within an area are based primarily on scientific quality. An informal peer review system exists, but final decisions rest with the scientific managers.

In-House Program

The Naval Research Laboratory (NRL), the Naval Research and Development Activity (NORDA), and the Naval Biosciences Laboratory (NBL) are the Navy's corporate research laboratories; however, the Naval Material Command R&D Centers and the Naval Medical R&D Command also have research laboratories. These laboratories have unique and critical roles in the overall process of linking diverse fields of science, within and outside the Navy, to naval technology and mission needs. Although in most fields each is one of several U.S. performing organizations, these labs are the primary sites of critical U.S. researches in a few broad areas.

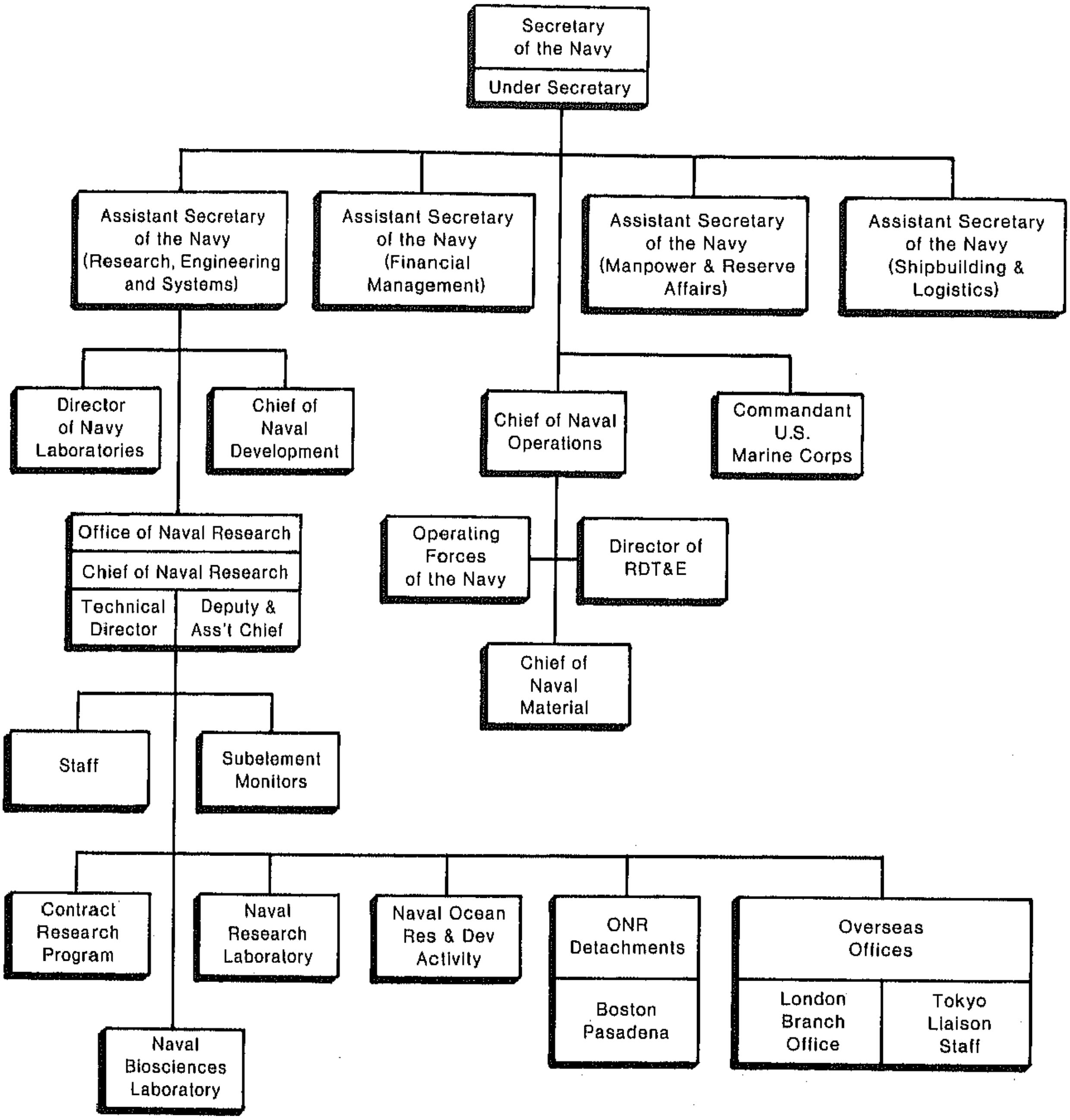

Fig. 23 — Navy research management structure

besides being a Navy corporate is the principal in-house laboratory of :arch funding at NRL is about 24% of ry's total funds, and it plays a major L's total operation. NORDA, the ity that emphasizes RDT&E in ocean technology, collocates about 37% of ds to research, while NBL collocates 80% of its total funds to research. Centers under the Chief of Naval lthough funded to a much lesser NRL in the 6.1 research area, are, as pectrum laboratories with expertise in science and engineering from basic fleet support. The research at these is intended to ensure the effective- Navy in conducting its mission now future. In brief, these centers, as n performers, contribute directly to as pertinent to Navy interests, take a inary approach not readily available act as important links to pertinent ried out in other places, and help to ch advances to naval problems.

n

ch is coordinated in various ways, government needs and according to and level of activities and interests in esearch fields. The Office of the retary of Defense Research and annually reviews the overall research nd actively coordinates with the ience Foundation and the U.S. scien- nity. Medical research is coordinated D committees and with the National f Health. Oceanographic research is with the National Oceanic and c Administration, as well as with the ience Foundation. Joint symposia are ther military services and government

ination is also accomplished through neans of professional scientific com- by ONR program managers who are active in professional affairs. Numerous relationships are maintained with industrial research and development firms to coordinate the transition of successful research results to industrial development. Industry may also request to use special in-house facilities for tests and evaluations of components and instruments; these requests are honored in accordance with DoD policy on technology transfer.

Technology

Research is interrelated with the Navy's Exploratory Development of Applied Research Program under the direction of the Chief of Naval Development. The program includes concept formation, analytical, and experimental efforts to

- identify and solve problems arising during development,
- identify technological opportunities which may stimulate the development of substantially improved or totally new operational capabilities, and
- demonstrate the usefulness of new discoveries to a degree which warrants their consideration for support under advanced development.

Technology areas of emphasis are as follows:

Tactical directed energy
Undersea warfare weaponry
Undersea target surveillance
Surface and aerospace target surveillance
Command and control
Countermeasures
Man/machine systems
Biomedical
Oceanography and atmospheric
Logistics, personnel, and training
Materials and aircraft
Electronic device
Chemical, biological, and radiological defense

Department of the Air Force

The Air Force Office of Scientific Research (AFOSR) is the sole manager of Air Force basic research and, therefore, plans, manages, implements, and controls this research. The Air Force basic research program, the USAF Defense Research Sciences (DRS) Program, is directed toward advancing the state-of-the-art in areas related to the technical problems encountered in developing and maintaining a qualitatively superior Air Force; in improving the performance, maintainability, and supportability, and lowering the cost of Air Force weapon systems; and in creating and preventing technological surprise.

In managing the DRS program, AFOSR created the USAF Plan for Defense Research Sciences which serves as the master guide for all Air Force basic research activity. This plan is written in response to the Air Force Systems Command (AFSC) Research Planning Guide which identifies the research objectives of the Air Force. The research objectives are grouped into eight technical areas: aerospace vehicles, computational sciences, electronics, geophysics, life sciences, materials, propulsion and power, and weaponry. Each technical area is divided into subareas. The Guide briefly describes each subarea and names points of contact.

AFOSR conducts a program of extramural research contracts and grants; manages three subordinate units; and oversees the research programs (in-house and extramural) of the Air Force Laboratories.

Over a period of several years, AFOSR has also conducted a program of interdisciplinary initiatives in areas of basic research especially important to the Air Force mission. These initiatives, which require a concentrated effort, include basic research in high interest areas, such as those listed below:

- Artificial intelligence
- Bioreactivity
- Defense against chemical agents
- Energy efficient aircraft
- Fast algorithms
- Gas turbine engine hot section
- Low speed take-off and landing
- Manufacturing science
- Optical signal processing
- Processing of spacecraft imagery
- Reliability of real systems
- Short wavelength laser sources
- Space propulsion and power
- Space surveillance and background radiation
- Spacecraft structures and materials
- Spacecraft survivability

Subordinate Units of AFOSR

These units are the European Office of Aerospace Research and Development (EOARD) in London, AFOSR Far East (AFOSR/FE) in Tokyo, and the Frank J. Seiler Research Laboratory (FJSRL) in Colorado Springs.

EOARD and AFOSR/FE gather information about foreign research and act as liaison between Air Force scientists and engineers and their foreign counterparts.

FJLSRL, located at the United States Air Force Academy, performs in-house research in selected areas. At present, these areas include optical physics, aerospace mechanics, fluid mechanics, and chemistry. Through FJSRL, faculty and cadets at the Academy have an opportunity to perform research. The faculty contributes expertise in addressing technical problems, and interested cadets may explore Air Force careers in research and development.

Extramural Program

AFOSR awards grants and contracts to universities, nonprofit organizations, and industry

for research in the areas of science and engineering related to the national security and the mission of the Air Force. Although these areas are not identical to the DoD disciplines previously discussed, they are similar. The 13 projects that the Air Force funds through AFOSR are:

- Astronomy and astrophysics
- Atmospheric sciences
- Biological and medical sciences
- Chemistry
- Electronics
- Energy conversion
- Fluid mechanics
- Human resources
- Materials
- Mathematics
- Physics
- Structures
- Terrestrial Sciences

The grants and contracts that AFOSR awards constitute 65% of the DRS program budget. Supported research originates from proposals submitted by scientists and engineers. AFOSR accepts or rejects proposals based on the significance of the proposed research to the Air Force, the originality and scientific merit of the proposal, the competence of the investigator, and the reasonableness of the proposed budget.

AFOSR's support of these proposals has produced scientific knowledge and new concepts for technological advances. Examples include advances in electronic computers, microwave technology, and antenna design; an understanding of hypersonic and transonic aerodynamics; development of the chemical laser, expression of control theory and an understanding of linear filtering; and an understanding of fracture and fatigue mechanics.

Laboratory Research Program

AFOSR funds research at the following Air Force Laboratories: Air Force Armament Laboratory, Air Force Geophysics Laboratory, Air Force Rocket Propulsion Laboratory, and the Air Force Wright Aeronautical Laboratories (includes Flight Dynamics Laboratory, Materials Laboratory, Avionics Laboratory, and Aero Propulsion Laboratory), Aerospace Medical Division (includes Air Force Human Resources Laboratory, and Air Force school of Aerospace Medical), and Air Force Weapons Laboratory, and Rome Air Development Center.

The Laboratories conduct in-house research, as well as award contracts for research that directly supports their in-house programs. Thirty percent of their funding comes from DRS program money. In a typical year, half of their funds is scheduled for in-house research and half for contracts.

Defense Advanced Research Projects Agency

The Defense Advanced Research Projects Agency (DARPA) is a separate agency within the Department of Defense and serves DoD as a "door opener" to new technological ideas. DARPA is entrusted with the corporate, or central, research function of DoD. Its function resembles that of a corporate research division in private industry, which is responsive to the highest levels of corporate authority. Its programs focus on proof-of-concept demonstrations of revolutionary approaches for improved strategic, conventional, rapid deployment, and sea-power forces, and on the scientific investigation into advanced basic technologies of the future. Thus, DARPA is able to explore the possible military benefits of new and unconventional concepts and technologies for all military services, without regard to the specific roles or missions which their applications might have.

DARPA's corporate investment strategy is guided by DoD's responsibility to maintain technological leadership in defense capabilities. DARPA is encouraged to assume high risks if it is convinced that, when the technology matures, a major advancement in military capability will be within reach. The agency was created by Public Law 85-325 in February 1958, partly because of pressures caused by the launching of Sputnik and partly in response to the urgent need for high-level attention to selected research projects stemming from promising advanced concepts and requiring long-range development. Figure 24 depicts the organizational structure.

Operations

DARPA operates in circumstances defined by defense policy and budgets, strategic arms negotiations, and a continuing need to maintain the credibility of the Nation's strategic deterrent capability and the viability of its tactical forces. To fulfill its responsibilities, DARPA selects for support only those R&D initiatives that promise to advance U.S. national security interests while lowering costs through technological advances, or to prepare the foundations for further technological progress.

DARPA's fiscal approach is to ensure funding at a level that does not compromise the attainment of the technical goals of the project. Because the project can move forward at a pace limited only by technical knowledge and human resources, this approach yields an early determination for the need of the R&D and its expected future success. DARPA proceeds with its initial investment in this manner: it accepts the risks, withdraws support from unproductive projects, and selectively extends the most promising projects into modest-scale demonstrations for evaluation. During the planning and conduct of these demonstrations, DARPA seeks increased participation by the military services in formulating the objectives and scenarios consistent with the criteria for evaluating and selecting military technology. DARPA executes its programs through military service agents and, where appropriate, also demonstrates technical feasibility and military usefulness in joint experiments and demonstrations with the military services. This joint participation facilitates the subsequent transition of selected technology programs to the military services for advanced development.

DARPA's programs are divided into two broad categories: basic technology projects and major demonstration projects. The basic technology projects focus on long-term research in six general areas that correspond to present technical office organization:

- Strategic Technology;
- Directed Energy;
- Tactical Technology;
- Information Processing;
- Defense Sciences; and
- Engineering Applications.

These areas form the basis of an investment strategy that is designed to contribute to a retention

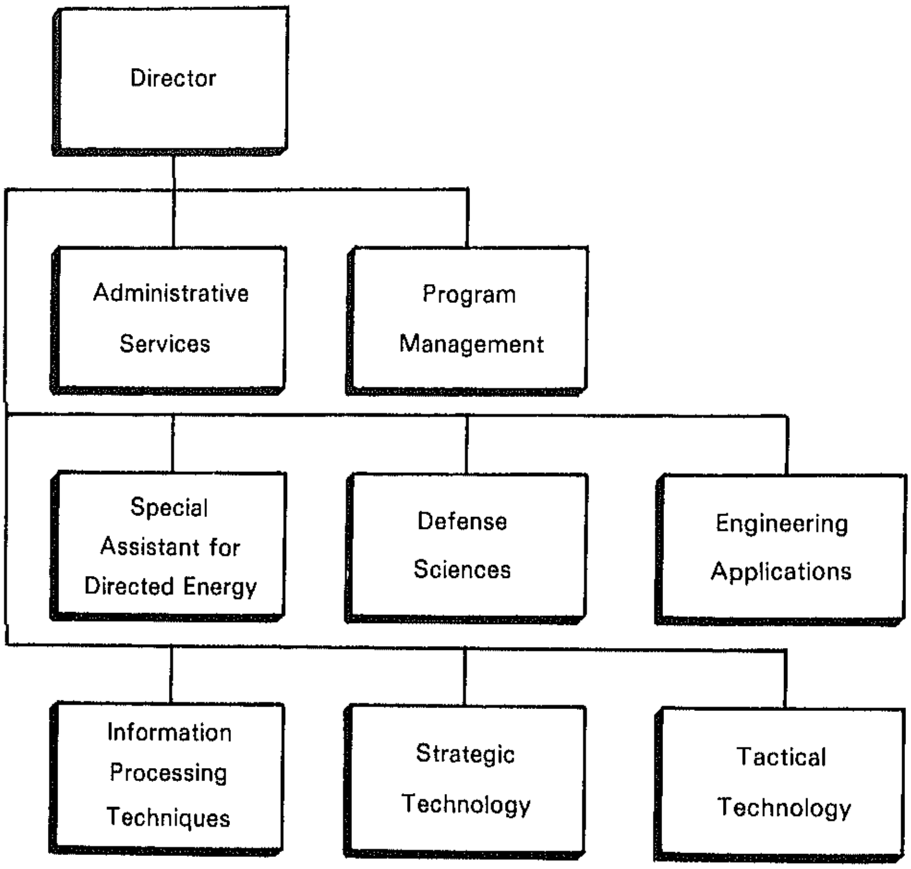

Fig. 24 — DARPA management structure

of the U.S. technological initiative in defense technology. As high-payoff technology areas mature, feasibility demonstrations are conducted, in cooperation with the military services, to move the technology rapidly through the development.

Strategic Technology Office

The Strategic Technology Office (STO) is committed to the development of the technology base for strategic concepts and analyses for offensive and defensive systems. These technologies include advanced surveillance systems for space-based and ground-based applications; advanced concepts for strategic weapons, strategic communications, submarine laser communications; and ocean surveillance, targeting, and control.

STO is emphasizing the development of IR and radar sensor technologies which will detect and track modern targets, provide simplified data processing on board the satellite, and employ modular structures in sensor design for cost efficiency.

Directed Energy Office

The directed energy program at DARPA is supporting advanced research in laser, microwave and particle beam devices, and associated beam control techniques. The program explores the feasibility of directed electromagnetic and particle beam technologies for tactical applications including beam weapons targeted against sensors and the identification and testing of new communications, target designation, and advanced surveillance concepts. Emerging technologies in directed energy beams also suggest significant new applications in material processing, lithography, and remote detection of chemical and biological agents.

Tactical Technology Office

The Tactical Technology Office (TTO) conducts innovative research and development of selected emerging technologies. TTO's programs are currently directed toward air and land warfare.

The air warfare research supports R&D initiatives intended to substantiate the feasibility of advanced technologies for manned and unmanned aircraft systems. The air warfare programs stress concept demonstration of technologies that apply to manned aircraft, both fixed and rotary wing systems, and unmanned platforms, to include cruise missiles and remotely piloted vehicles. Research efforts include investigating advanced aerodynamics, structures and materials, flight control concepts and designs, low- and high-speed propulsion systems, and revolutionary man-machine interface opportunities that approach total air vehicle automation. Acceptance of high technological risk to achieve these advancements is an important characteristic of air warfare research. Representative of this are the X-29 Advanced Technology Demonstrator, the X-Wing Demonstrator, and Advanced Cruise Missile Technology development. These programs are integrating several state-of-the-art aerodynamic, structural, and flight control concepts, and offer potential breakthroughs in air vehicle performance.

The land warfare programs are dedicated toward the development of tactical systems for the next generation. The overall program goal is to substantively advance conventional tactical combat capabilities with careful consideration to both realistic cost and service manpower constraints.

Information Processing Techniques Office

The Information Processing Techniques Office (IPTO) is dedicated to the development of advanced information processing and computer communications technologies for critical military and national security applications. In this area, IPTO's research program is the largest in the Federal Government; it includes both basic research and exploratory development. IPTO's central purpose is to advance the technology and options for the application of this technology to command, control, and communications (C^3); intelligence (I); and military information processing.

IPTO focuses its programs in three general areas of research: (1) basic computer science; (2) command and control; and (3) strategic computing technology.

During FY 1984, IPTO initiated an important program in strategic computing. By seizing opportunity to leverage recent advances in artificial intelligence, computer science, and microelectronics, IPTO plans to create a new generation of "machine intelligence technology" for application to defense programs such as autonomous vehicles, battle management, and a pilot's associate being carried out in the Engineering Applications Office. This new technology will have unprecedented computational capabilities and promises to greatly increase our defense capability as it emerges during the coming decade.

Defense Sciences Office

The Defense Sciences Office (DSO) is committed to the support of advanced R&D initiatives which promise benefits from many disciplines. The objectives of R&D efforts in this field are to support national security in the area of nuclear monitoring, to support the military services in developing advanced materials leading to new structures or electronic and electro-optic components and devices, and to advance system technologies for improved military operations. To achieve these objectives, DSO is divided into three program areas: Geophysical Sciences, Materials Sciences, and Electronic Sciences.

Geophysical Sciences Division—The geophysical sciences program pursues R&D to provide technological options for improving test-ban treaty monitoring. The Geophysical Sciences Division (GSD) supports R&D efforts which address major problems associated with the detec-

tion and characterization of foreign nuclear explosions. Major areas requiring research include the detection of low-yield underground bursts and their unambiguous differentiation from earthquakes. Other major problem areas are accurate estimations of the yield of underground explosions and improved methodologies for determining the presence and characteristics of nuclear bursts in remote locations on earth or in space. GSD supports R&D efforts in geophysics and related disciplines, and in the development of advanced instrumentation for detecting and measuring nuclear-explosion-related phenomena.

Materials Sciences Division—The Materials Sciences Division (MSD) supports R&D initiatives with the objective of developing materials or structures that offer better performance, greater ease of use, or lower cost while achieving greater strength, greater durability, lighter weight, or greater fuel efficiencies.

Specific areas of MSD's research presently include rapid solidification technology, armor and anti-armor technologies, penetration mechanics, laser counter-measure materials, optical materials, carbon-carbon composites, and structural polymers.

MSD also explores advanced materials processing technologies in many areas; future turbine technology, structural ceramics from polymer precursors, and metal-matrix composite for space and weapon system applications are examples. In addition, MSD supports research in the dynamic synthesis and processing of high-value materials for military applications.

Electronic Sciences Division—The Electronic Sciences Division (ESD) supports R&D initiatives in the broad areas of electronic, optical, and biological materials and their processing that may provide the keys to significant advances in the combat effectiveness of general purpose and strategic forces, and in the development of technological advances that contribute to reducing the life cycle costs of weapons systems. Specific areas of current ESD focus include: advanced biochemical technology for ultrasensitive chemical and bacteriological detectors and to exploration of applications for biochemical compounds; focal plane array materials and device structures; gallium arsenide circuit technology; optical processing and computation, and new concepts and processing for supercomputing.

Survivability in hostile environments is being pursued by focusing efforts in low-power, radiation-hardened gallium arsenide circuits. Gallium arsenide technology is progressing beyond the laboratory stage towards a pilot line fabrication facility which produces more than 100 wafers per week for defense applications. This technology will provide a 1,000 times greater radiation total dose and dose rate resistance to ionizing radiation than silicon—an important capability for space-based applications.

Engineering Applications

The Engineering Applications Office (EAO) conducts highly innovative and well-focused research and development programs that apply advanced science and technology concepts to critical national security problems. These primarily involve advanced computer technology and associated applied mathematics, and typically produce concept demonstration systems. Major advances in multiprocessor computer systems and artificial intelligence technology resulting from research supported by the Information Processing Techniques Office hold the key to a new generation of defense weapons systems and command, control and intelligence systems with vastly greater capability than those currently employed by DoD.

The technologies of multiprocessor computer systems and artificial intelligence are being used in three major EAO research programs. The first is to develop an autonomous land vehicle, with potential Army application. On-board computation will be provided by a powerful multiprocessor system. It will run a large expert system to plan the route for the vehicle, taking into account such disparate factors as weather, intelligence observations, terrain, and the mission, whether for resupply or reconnaissance. Further, the vehicle will be guided by a multi-spectral

vision system that will be used to locate roads and avoid obstacles. The technology in the vehicles will be applicable to other autonomous systems, including air, sea, and undersea vehicles.

The second area being pursued is the development of an advanced battle management system, initially in a naval context. A central function will be real-time data fusion using a large expert system running on a multiprocessor system. Data are often incomplete, contradictory, or ambiguous; problems are currently resolved by military personnel who are frequently overwhelmed by the quantity of data available from new sensor sources. The speed of computation of the multiprocessor system technology will make it possible to keep up with the data flow under crisis conditions. In addition to data fusion, the system will provide a natural English language interface, and will further use natural language understanding technology in order to interpret the constant flow of military messages. This work is being conducted jointly with the Strategic Technology Office.

The third area being developed is a fighter pilot's associate to aid in the cockpit, which will have application in all of the services, but particularly the Air Force. An expert system running on a flyable multiprocessor in the cockpit will continuously monitor on-board systems to advise the pilot on the safety of the aircraft; will examine real-time sensor data to identify distant targets and will aid in planning flight paths based on threats and mission objectives. In addition, it will have a speech interface to ease interaction under time critical conditions. This project is being conducted jointly with the Tactical Technology Office.

In addition, EAO has innovative programs in a number of other areas. Robotics and manufacturing technology occupy a central position, and include work on actuators, sensors, control algorithms, and overall systems. This area will also benefit from the new multiprocessor systems to provide real-time computational capabilities.

Appendix A
Tabulated Data

The following tables contain data relating to the DoD research program. The data both describe the program itself and show its relation to the rest of the RDT&E program and to the national research effort.

Figure A-1 shows that DoD Research makes up 3% of the total RDT&E budget. The funding history of the research portion of the DoD RDT&E budget is displayed in Figure A-2.

Figure A-3 shows the distribution of basic research funds by agency for 1985.

Table A-1 shows the distribution of the individual 6.1 research program projects according to the size of funding allocated to them.

Table A-2 displays how the DoD research budget is distributed among research performers; Table A-3 refers specifically to the support of university research programs.

Table A-4 shows the funding history of basic research by discipline and by sponsoring agency for fiscal years 1982-86.

Type of RDT&E Activity	Funding ($M) FY 1985	FY 1986	Growth (%)
Research	861	971	12.8
Exploratory development	2,261	2,555	13.0
Advanced development	6,837	11,683	70.9
Engineering development	10,917	10,747	−1.6
Management and support	2,436	2,744	12.6
Operational systems development	8,140	10,580	30.0
Total	$31,452	$39,280	24.9

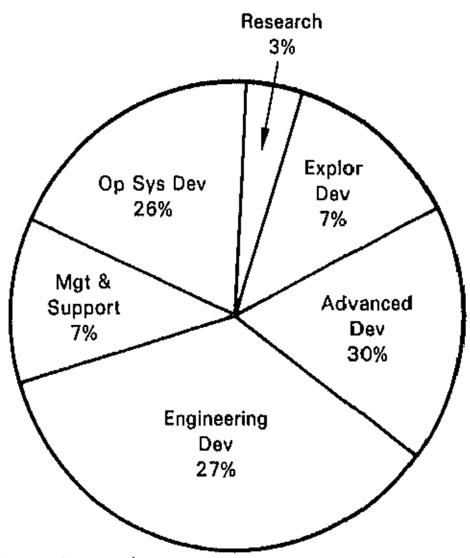

Fig. A-1 — RDT&E by activity type (millions of dollars)

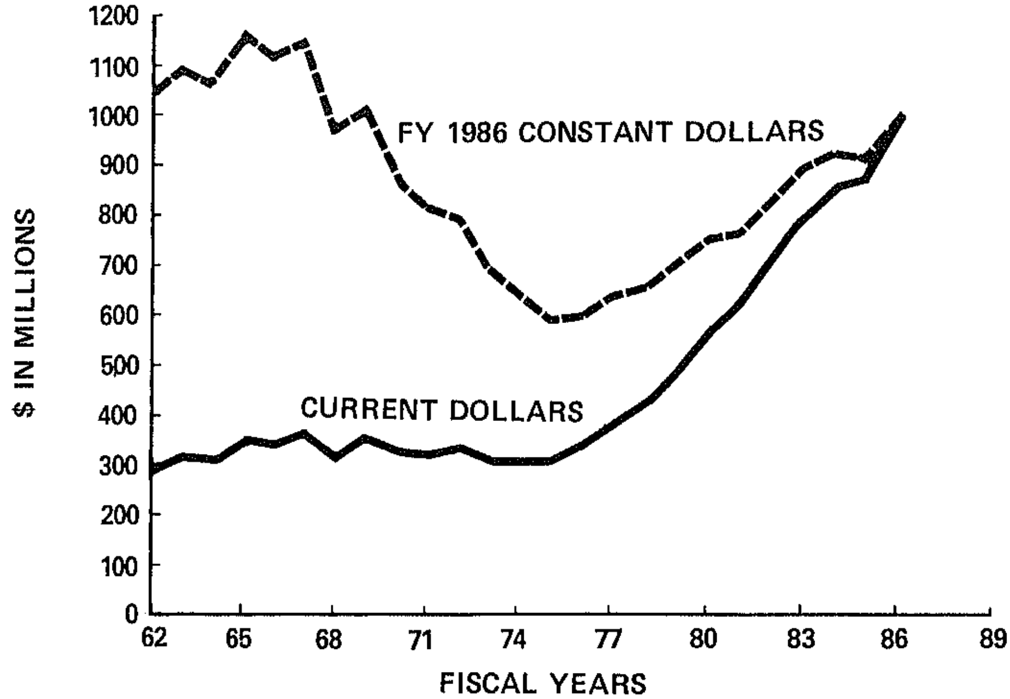

Fig. A-2 — Funding history of DoD research budget

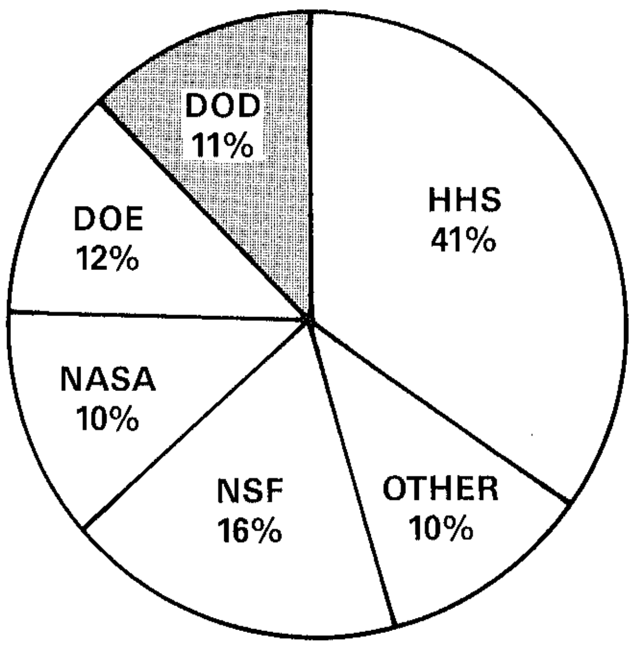

Fig. A-3 — Perspective on DoD research distribution of basic research funds by agency (FY 1985 estimate)

Table A-1—Funding Size Distribution of Individual 6.1 Research Projects Percentage of Projects by Size in $K (FY 1984)

	0-50	50-100	100-200	Over 200
Army	29	54	13	4
Navy	2	7	15	76
Air Force	37	33	21	9

Table A-2 — Research Performers (FY 1985 Estimates)

Performers	Basic Research (6.1)	All R&D
Universities	50%	3%
Government labs	30%	22%
Industry and federal contract research centers	20%	75%
Total funds	$861M	$31B

Table A-3—Allocation of Research Funding to Universities

Organization	Funding ($)M FY 1982	FY 1983	FY 1984 [Est.]
Army	85	90	96
Navy	134	155	178
Air Force	75	88	98
DARPA[a]	39	54	62
Total	$333	387	434

[a] DARPA—Defense Advanced Research Projects Agency

Table A-4—Department of Defense Funding For Basic Research by Service and Discipline, FY 1982 to FY 1986 (Budget Authority in $M)

	ARMY					NAVY					AIR FORCE					DARPA				
FISCAL YEAR	82	83	84	85	86	82	83	84	85	86	82	83	84	85	86	82	83	84	85	86
PHYSICS, RADIATION SCIENCES ASTRONOMY AND ASTROPHYSICS	18.5	19.0	19.0	21.5	23.8	37.3	40.9	43.3	39.4	50.0	20.0	21.2	25.9	27.0	30.6					
MECHANICS AERONAUTICS AND ENERGY CONVERSION	15.1	18.2	18.7	17.4	20.4	28.6	31.7	31.2	34.5	35.0	29.8	31.6	34.9	39.6	40.6					
MATERIALS	14.8	15.1	16.3	17.7	19.3	23.0	24.0	28.9	30.3	33.3	18.1	17.7	22.4	23.3	24.5	14.4	22.0	19.7	16.8	20.0
ELECTRONICS	20.3	21.3	24.5	26.3	29.1	27.0	27.9	27.7	32.6	32.5	16.2	16.7	21.8	20.0	23.1	26.4	23.3	29.6	20.0	21.2
OCEANOGRAPHY	–	–	–	–	–	52.0	50.2	53.6	54.4	59.9	–	–	–	–	–					
BIOLOGY AND MEDICAL SCIENCES	36.9	44.5	48.8	52.2	61.5	17.9	17.7	18.9	20.7	21.0	8.1	8.3	8.2	9.9	10.8			2.0	2.0	2.0
CHEMISTRY	22.2	23.2	23.3	24.9	27.7	17.1	18.2	20.3	22.5	24.3	13.8	16.9	18.1	19.6	22.7					
MATHEMATICS AND COMPUTER SCIENCES	13.8	13.5	14.9	15.3	17.4	22.2	29.1	27.5	33.0	31.5	12.7	15.1	17.6	19.0	20.3	35.1	42.5	46.5	28.7	34.2
TERRESTRIAL SCIENCES	5.3	6.1	6.9	7.2	9.9	14.1	17.7	17.7	16.0	17.8	2.4	2.3	2.7	2.9	3.1	2.2	2.9	3.1	2.2	2.3
ATMOSPHERIC SCIENCES	5.5	7.9	8.5	8.9	9.8	6.5	6.4	6.7	8.4	11.0	8.9	9.6	11.2	12.3	13.1					
BEHAVIORAL SCIENCES	4.2	4.8	5.2	7.7	8.0	9.3	10.3	10.0	13.0	12.8	6.2	5.3	6.2	6.6	7.5	14.1	12.9	12.8	12.8	14.9
UNIV. INSTRUMENTATION	–	10.0	10.0	10.0	10.0	–	10.0	10.0	10.0	10.0	–	10.0	10.0	10.0	10.0					
SPECIAL STUDIES	–	2.0	–	–	–	–	1.3	–	–	–	–	–	–	–	–					
ILIR	21.5	21.9	21.9	24.4	25.3	21.5	23.3	23.4	25.0	26.3	11.3	12.6	13.1	14.9	17.4					
UNIVERSITY RESEARCH INITIATIVE	–	–	–	–	6.1	–	–	–	–	6.2	–	–	–	–	6.2	–	–	–	–	6.2
TOTALS	178.1	207.5	218.0	233.5	268.3	276.5	308.7	319.2	341.2	371.7	147.5	167.3	192.1	203.6	230.0	92.5	103.6	113.7	82.5	100.8

Appendix B

Points of Contact in Department of Defense Research Program

Department of Defense

Director for Research and Laboratory Management
Office of the Under Secretary of Defense
for Research and Engineering
The Pentagon, Room 3E 114
Washington, DC 20301-3080
202-697-3228

Army

Deputy for Science and Technology
Office of the Assistant Secretary of the Army
(Research, Development and Acquisition)
The Pentagon, Room 2E 673
Washington, DC 20310-0103
202-695-7674

Director of Army Research
Office of the Deputy Chief of Staff (Research,
Development and Acquisition)
ATTN: DAMA-ARZ-D
The Pentagon, Room 3E 363
Washington, DC 20310-0632
202-697-3558

Director
U.S. Army Research Office
ATTN: AMXRO-TS
Research Triangle Park, NC 27709-2211
919-549-0641

Research and Development Office
Office of the Chief of Engineers
ATTN: DAEN-RDZ-A
20th Street and Massachusetts Avenue, N.W.,
Room 6208
Washington, DC 20314-1000
202-272-0254

Assistant Surgeon General for Research
and Development
Office of the Surgeon General
ATTN: DASG-RDZ
The Pentagon, Room 3E 474
Washington, DC 20310-2300
202-697-1120

Technical Director
U.S. Army Research Institute for the Behavioral
and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333-5600
202-274-8636

Navy

Deputy for Research Applied and Space
Technology
Office of the Assistant Secretary of the Navy
(Research, Engineering and Systems)
The Pentagon, Room 4D 745
Washington, DC 20350-1000
202-694-5090

Technical Director
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000
202-696-4262

Air Force

Deputy for Research and Development
Office of the Assistant Secretary of the
Air Force (Research, Development and
Logistics)
The Pentagon, Room 4D 977
Washington, DC 20330-1000
202-695-2317

Technical Director
U.S. Air Force Office of Scientific Research
Bolling AFB
Washington, DC 20332-6448
202-767-5017

DARPA

Deputy Director for Research
Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209-2308
202-694-3035

SAUDI ARABIA, KINGDOM OF

ECONOMIC BACKGROUND

Size of Fleet: 35 vessels of 1,054,000 dwt. tons.

Tankers	:	31% of vessels; 90% of tonnage
Bulk Carriers	:	0% of vessels; 0% of tonnage
Freighters	:	60% of vessels; 9% of tonnage
Combination Carriers	:	9% of vessels; 1% of tonnage

Foreign Trade: (1976)

		exports	imports
value (million US$)	:	$36,361	$11,812
commodities	:	petroleum and petroleum products	manufactured goods, transportation equipment, construction materials, and processed food products
trade partners	:	Japan, U.S., France, Italy, West Germany, U.K.	U.S., Japan, West Germany
GNP (1975)	:	$33,240,000,000	
GNP/capita (1975)	:	$4,010	

GOVERNMENT AIDS

Subsidies

Saudi-flag vessels receive markedly lower bunkering rates.

Cargo Preference

A Royal Decree requires that Saudi-flag vessels be used provided they are equal in ability, quality and performance.

Another law calls for the transport of 25 percent of all Saudi oil cargoes in Saudi-owned tankers.

SINGAPORE

ECONOMIC BACKGROUND

Size of Fleet: 474 vessels of 9,758,000 dwt. tons.

Tankers	:	20% of vessels; 57% of tonnage
Bulk Carriers	:	10% of vessels; 18% of tonnage
Freighters	:	66% of vessels; 24% of tonnage
Combination Carriers	:	4% of vessels; 1% of tonnage

Foreign Trade: (1976)

		exports	imports
value (million US$)	:	$6,594	$9,070
commodities	:	petroleum products, crude rubber, electrical machinery	crude rubber, petroleum and petroleum products, non-electrical machinery
trade partners	:	Malaysia, U.S., Japan, Hong Kong, Australia	Japan, Saudi Arabia, Malaysia, U.S.

GNP (1975)	:	$5,500,000,000
GNP/capita (1975)	:	$2,450

The Port of Singapore is one of the busiest ports with some 40,000 ships, calling from, and departing to, all parts of the world annually. It is administered by the Port of Singapore Authority, a statutory board under the purview of the Ministry of Communications.

At Keppel Harbour, there are 4,400 metres of marginal wharves capable of accommodating at least 30 large conventional vessels simultaneously. The container terminal which began operations in 1972 has three berths totalling 920 metres for third-generation container ships and one 220-metres berth for container feeder vessels. Plans are underway to construct two additional container berths totalling 640 metres and a large 64-hectare container depot with freight stations for the consolidation of cargo and the unstuffing of containers. In

the northern part of Singapore, at Sembawang, the PSA operates an ocean gateway with five berths for handling low-value high volume homogenous cargoes such as timber and rubber. Berthing facilities are available at the Telok Ayer Basin and Pasir Panjang wharves for shallow-draught coastal vessels as well as lighters and barges carrying cargo from or to vessels in the anchorages. The Pasir Panjang Wharves is a new ocean gateway on the west coast of Singapore, which became operational in 1974. There are some 2,100 metres of wharves for lighters, bargers and coastal vessels. In Jurong, there is an ocean gateway with 5 berths totalling 1,100 metres for handling bulk cargoes and homogenous break-bulk cargoes.

The Port is backed by other facilities and services such as free trade zones totalling 210 hectares to enable dutiable goods to be imported, stored, processed and re-packed for re-export without the payment of import duties. There are also facilities for receiving and treating slops. Warehousing facilities are provided outside the free trade zone at Nelson Road and Depot Road.

The shiprepairing and shipbuilding industries have been growing steadily. The Jurong Shipyard Limited, partially state-owned, now has a dry dock to take 90,000 dwt. vessels and a dry dock to take 300,000 dwt. vessels. The Sembawang Shipyard Limited, the former British Naval Dockyard is a government-owned shipyard with public share participation. It has completed during 1975 a shiprepairing drydock designed for 400,000 dwt. vessels. Hitachi Zosen Robin Shipyard Pte., Ltd., has a 300,000 dwt. drydock and has plans to build another 150,000 dwt. dock. Mitsubishi Singapore Heavy Industries, Pte. Ltd., the sister company of Jurong Shipyard, Ltd., after completing the construction of a series of 11 freedom type multipurpose dry cargo vessels of 14,800 dwt. each, is now building the next series of 91,600 dwt. tankers. The first vessel of this series had been successfully delivered to her owner in January, 1976 for registration with the Registry of Singapore Ships in Singapore.

During 1975, Singapore-flag vessels carried 7 percent of Singapore's seaborne trade (7.7 percent of imports and 6.1 percent of exports).

GOVERNMENT AIDS

Tax Benefits

Ships registering under the flag of Singapore must pay an initial registration fee of $2.50 per new registered ton. A refund of 50% of the annual tonnage tax paid is granted to

foreign-going vessels which maintain at least 25% of their crew who are Singaporeans for a continuous period of one year. The Government of Singapore guarantees that these fees will not be increased during twenty years following initial registration.

Effective from January 1, 1970, any shipping enterprise which registers a ship in Singapore will be exempted from income tax on its income derived from the operation of such a ship.

Loans and Interest on Loans

Deferred credit financing is available to shipowners through the local shipyards for the purchase of locally-built oceangoing vessels of over 5,000 dwt. Interest rate is on a fixed basis and follows the rate set by the OECD. The government has recently extended a new line of credit to be administered by The Development Bank of Singapore, Ltd., (DBS). The scheme assists the shipowner in purchasing locally-built vessels below 5,000 dwt. Interest rate of 9.5 percent per annum or thereabouts is on a fixed basis during the tenure of the loan. For both schemes, the loan value can reach a maximum of 50 percent of the contract value of the new ship and the loan is repayable over a period of up to 7 years after delivery of the vessel. Additional financing in excess of 50 percent of the contract value may be made available to the shipyard on commercial terms. Interest rate would most likely be on a floating basis.

For establishment of new shipyards or modernization of existing yard facilities the DBS also extends loans at 9.5 percent to be repaid within 8 years.

Deferred Credit for Financing Vessels Built in Singapore

The recently announced ship financing scheme is available for the construction of vessels under 5,000 dwt:

Loan Quantum	:	Up to a maximum of 50 percent of contract value.
Interest Rate	:	Fixed interest rate of 9.5 percent or thereabouts during the tenure of the loan.
Repayment	:	Up to a maximum of 7 years after delivery.
Disbursement	:	In accordance with work-in-progress.

Currency	:	In Singapore Dollars.
Type of Vessels	:	Generally for vessels over 100 grt and tugboats of over 500 bhp. Each case will however be decided on its own merits. Military craft and all types of drilling equipment are excluded.

The scheme is to partially finance deferred credit granted by local shipyards to the owners of the vessels under construction.

The vessels to be financed must be completely built in Singapore.

In the event that the deferred credit granted by a shipyard exceeds 50 percent of the contract value, additional financing may be made available to the shipyard on commercial terms. Interest rate would most likely be on a floating basis.

Financing of yard construction expansion and yard equipment:

Terms

Amount	:	50 percent of cost of facilities
Interest Rate	:	9.5 percent or thereabouts
Duration	:	Up to 8 years

GOVERNMENT OWNERSHIP

The government owns the Neptune Orient Lines, Ltd., the Keppel Shipyard, and the Sembawang Shipyard. It also has partial ownership of the Jurong Shipyard and a number of smaller shipyards.

Other

The Singapore Shipping Association and the Indonesian Shipowners Association have signed an agreement calling for a 50/50 sharing of the cargo to be carried by association members in the trade between the two countries.

SOUTH AFRICA

ECONOMIC BACKGROUND

Size of Fleet: 50 vessels of 535,000 dwt. tons.

Tankers :	6% of vessels;	11% of tonnage
Bulk Carriers :	8% of vessels;	16% of tonnage
Freighters :	84% of vessels;	70% of tonnage
Combination Carriers:	2% of vessels;	3% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$7,874.1	$6,769.4
commodities	gold, diamonds wool, fruit, copper	machinery, transport equipment, textiles, petroleum products
trade partners :	U.K., Japan, West Germany, U.S.	U.S., West Germany, U.K., Japan

GNP (1975) : $32,270,000,000
GNP/capita (1975) : $1,270

Foreign trade is of vital importance to South Africa, whose imports are equal to nearly 19 percent of GDP and whose exports provide nearly 14 percent of GNP. Consequently shipping is of great interest to South Africa. The merchant fleet is growing, as is the shiprepair industry which has benefited from the increased traffic around the Cape of Good Hope resulting from the Suez Canal closure. Cape Town and Durban are the centers of activity in South African shiprepair and shipbuilding.

Two container berths are operational at Cape Town. The container facilities at this port provide, among others, stacking space for 13,900 containers for international trade and 4,240 containers used in the coastal trade.

At Durban, South Africa's biggest port, a container terminal has been established on a 125.7 hectare site, with five deepsea container berths. In addition, the port has a terminal grain elevator of 38,100 ton storage capacity, with a shipping gallery. Electrically driven appliances for the loading of coal, anthracite, coke, manganese ore, iron ore and ferro-alloys, are also available.

At Port Elizabeth, container facilities capable of handling 5,000 containers per month, have been provided.

Saldanha Bay has been developed as an iron ore export terminal. The habour was completed in September 1976 and in its first year of operation, more than ten million tons of iron ore have been shipped from the port. Apart from iron ore, the new harbour will also be used for the shipment of ore concentrates, zinc, lead, copper and certain containerised cargoes.

Richards Bay was the first new South African harbour to be constructed since 1910 at a total investment, including a new 500 km rail line, of R700 million. The harbour became operational on 1 April 1976 and is presently being used mainly for the export of coal.

South African-flag vessels carried approximately 32 percent of South Africa's oceanborne foreign trade in 1977 (38 percent of imports and 26 percent of exports).

GOVERNMENT AIDS

Construction Subsidy or Aid

1. The Government has promulgated measures for the promotion of the South African Shipbuilding industry as follows:

(a) the level of any subsidy granted will be at a fixed rate of 25 percent of the contract price in respect of ships of 500 gross registered tons and larger but smaller than 6,000 gross registered tons;

(b) in respect of ships of 200 gross registered tons and larger but smaller than 500 gross registered tons such subsidy will be at a fixed rate of 10 percent of the contract price;

(c) a higher rate of assistance may, in exceptional cases, be considered and the extent of the assistance to be granted in such cases will be determined in accordance with the merits of each application. Assistance

may likewise be considered in exceptional cases in respect of ships smaller than 200 and larger than 6,000 gross registered tons and a subsidy may also be considered in respect of contracts for Government Agencies when the extent of the subsidy will depend on the position after the difference between the overseas tender price plus the existing import duty and the local tender price less preference afforded in respect of local content has been established;

(d) the subsidy will, except in respect of contracts for Government Agencies, in future be based on the local contract price only and comparable overseas tender prices will not be insisted upon;

(e) assistance in respect of foreign contracts is considered, on the same conditions as outlined above, but all applications will have to be submitted beforehand to the Treasury for approval;

(f) the quantum of assistance in each case will not be directly dependent upon the profitability of the shipbuilder concerned, but the position will be reconsidered in the event of shipyards earning more than 7.5 percent (after tax) on paid-up capital plus share premiums and reserves employed in its shipbuilding activities.

2. (a) The government will, where necessary, guarantee the repayment of capital and interest on loans negotiated by shipyards for extending credit to approved buyers, on condition that the credit allowed shall not exceed 80 percent of the contract price, that the credit will be limited to a maximum period of 10 years, and that the amount will be systematically repaid over this period.

(b) the aid scheme was extended since 6 March 1978 to include also the rebuilding and reconstruction of ships and other floating vessels and installations with a <u>minimum</u> building cost of R500,000. Preference will, however, be given to the construction of new vessels.

(c) the government will also subsidize the interest on the aforementioned loans to such an extent that the prevailing interest rate on the loan will be reduced by 2 percent per annum.

3. The subsidy scheme will be in operation until 1981 and will thereafter be reviewed.

4. In addition to the subsidy scheme as outlined above, the following measures have also been taken:

(a) the imposition of an import duty of 20 percent ad valorem on all ships which are classifiable under customs tariff items 89.01.40, 89.01.90, 89.02 and 89.03.10 upon the understanding, however, that the Minister of Economic Affairs may, if he is convinced that such a ship cannot be built locally within the framework of the subsidy scheme, grant a rebate of the duty on ships classifiable under rebate items 411.00/89.01 and 411.00/89.02 for such purposes and subject to such conditions as he may prescribe;

(b) provision for a rebate of customs duties on materials, equipment and spare parts used for the building and equipment as well as for the rebuilding and repair of ships but with due regard to the country's treaty obligations. Shipbuilders wishing to come into consideration for this rebate should contact the Secretary for Customs and Excise.

Tax Benefits

Act 58 of 1962 provides for an initial allowance of 40 percent of the cost of acquisition of a new ship (or, in certain circumstances, a ship which is not a new ship) and subsequent annual allowances of 10 percent of such cost until the total of the allowances made reaches an amount equal to the cost of such ship.

Cargo Preference

All goods shipped from the United Kingdom or the continent of Europe to South Africa for government use must be shipped in vessels operated by the South and South-East African Conference Lines, of which SAFMARINE is a member.

Government Ownership

The South African Marine Corporation (SAFMARINE) is controlled approximately 37.5 percent by the South African Industrial Development Corporation, a government-controlled organization.

The South African Sugar Carriers was formed by SAFMARINE and the South African Sugar Association.

SPAIN

ECONOMIC BACKGROUND

Size of Fleet: 474 vessels of 9,498,000 dwt. tons.

Tankers	:	25% of vessels; 66% of tonnage
Bulk Carriers	:	13% of vessels; 21% of tonnage
Freighters	:	55% of vessels; 12% of tonnage
Combination Carriers	:	7% of vessels; 1% of tonnage

Foreign Trade: (1976)

		exports	imports
value (million US$)	:	$8,727	$17,462
commodities	:	footwear, textiles, machinery, chemicals, furniture	machinery, grains, minerals, chemicals, manufactures
trade partners	:	France, West Germany, U.S., U.K.	U.S., West Germany, Saudi Arabia, France

GNP (1975)	:	$97,140,000,000
GNP/capita (1975)	:	$2,750

Spain has a particular interest in international shipping because most of the country's foreign trade is oceanborne. During 1976 Spanish-flag vessels carried 46.2 percent of Spain's oceanborne foreign trade (53.6 percent of imports and 17.5 percent of exports).

Spanish ports handled an estimated 191,000,000 tons of cargo in 1976, and may be required to handle 290,000,000 tons by 1980. The port at Bilbao is being expanded to accommodate vessels of 150,000 dwt. tons fully-laden or partially-laden vessels of 500,000 dwt. tons.

Spain's shipbuilding industry has been one of Spain's most dynamic industrial sectors. Spanish shipyards delivered 1,506,400 gross tons in 1974, and are expected to deliver 3,000,000 gross tons in 1980. The largest shipbuilding firm is the partially government-owned Astilleros Espanoles with eight shipyards. The shipbuilding industry is being restructured because of the depressed market conditions.

Spain's merchant fleet is now the fifth most modern in the world. Some 50% of its tonnage is under 5 years old and 79% under 10.

GOVERNMENT AIDS

Operating Subsidy or Aid

(A) High seas shipping: Annual subsidies are paid to two private companies for special services in the national interest of the Spanish State.

(B) Coastal shipping: In accordance with Spanish Law, a company has the right to be paid for the losses generated in the operation of coastwise trade since it is considered a public utility.

Construction Subsidy or Aid

By law of May 12, 1956, shipowners who purchase ships in Spanish shipyards receive a discount from the government. This amounts to 9 percent of the value if the ship is completely constructed in Spain and 6 percent if the propulsion system is imported. These subsidies are applied to compensate for the high duty rates that the Spanish shipbuilders have to absorb in accordance with customs protection given to materials and equipment produced in Spain.

In line with OECD commitment, aids to shipyards will be progressively reduced, and completely eliminated by November 1, 1975. This covers the following areas: direct building subsidies, customs tariffs or any other import barrier, discriminatory official regulations or internal practices, specific aid for investment in and restructuring of the domestic shipbuilding industry. An attempt will also be made to trim government assistance for ship export credits.

A Royal Decree in June 1976 made available shipbuilding loans for up to a total of 1,000,000 grt. on a once-and-for-all basis. These loans are to be financed over a period of 8 to 12 years at an interest rate of 7.5 to 8 percent. However, this interest rate may be raised to 11 percent.

Export Credit for Ships

The private banks and the Banco Exterior provide export credits covering 70 percent of the contract price, for 7 years at 6.9 percent, to which must be added various charges making a final gross rate of 8 percent.

Loans and Interest on Loans

Private banks make loans to Spanish owners on approximately the same terms as for export credits. The Construction Credit Bank may participate in such loans up to 25 percent for the building of ships of over 8,000 gross tons.

Modernization of Yards

Government approval must be obtained for expansion or conversion of shipyards.

Tax Benefits

About 12 percent of the total cost of the shipbuilding industry represents indirect taxation. Under the general export policy, all shipbuilding is eligible for a refund equal to this percentage, calculated after deduction of the customs duty rebate mentioned below.

Customs Duty Exemption

Imported material for incorporation in ships for export is considered as a temporary import and is exempt from customs duty. To take account of customs duties paid on imported material and equipment for ships for the domestic market a rebate of 7 percent is granted which partly offsets these duties; the rebate is reduced to 4.5 percent in the case of imported propulsion gear and for fishing vessels. In the case of ships for export, the rebate is calculated after deducting from the value of the ship the value of materials imported under the system governing temporary imports.

Cargo Preference and Cabotage

Spain restricts to national vessels, through government monopolies, many imports such as petroleum, tobacco, and cotton. When Spanish-flag ships are subjected by another country to measures contrary to free competition they shall have the right to apply similar measures in return.

Coastwise trade is reserved to Spanish-flag ships.

Import Restrictions

Imports of ships from all countries are subject to prior procurement of an import license. These are granted with some reluctance, but some ships are nevertheless imported.

Government Ownership

Spanish government participation in shipping companies represents about 11 percent of the total number of ships of 100 gross tons and over. These ships are operated primarily through the INI-owned Empressa Nacional "Elcano" and the state-owned Compania Arrendataria Monopolio de Petroleos S.A. (CAMPSA). The government purchased the Transmediterranea Shipping Line.

The government controlls 100% of Bazan shipyards, and 50% of Astilleros Espanoles (formed by the merger of one public and two private yards) and the Astano Company.

Other

There are no strictures imposed on the day to day running of fleets by the Spanish government. However, certain stipulations are laid down for fleet development. New buildings must emanate from Spanish yards. Vessel acquisition must generally be confined to Spain. Spanish owned tonnage must be under home registration. There is no provision for foreign nationals to be employed on Spanish vessels. Marine insurance is confined to the domestic market.

SWEDEN

ECONOMIC BACKGROUND

Size of Fleet: 329 vessels of 13,717,000 dwt. tons.

Tankers	:	27% of vessels; 56% of tonnage
Bulk Carriers	:	27% of vessels; 34% of tonnage
Freighters	:	44% of vessels; 10% of tonnage
Combination Carriers	:	2% of vessels; 0% of tonnage

Foreign Trade: (1976)

		exports	imports
value (million US$)	:	$18,436	$19,157
commodities	:	lumber, woodpulp and paper, iron and steel, machinery, ships	machinery, petroleum products, foodstuffs, chemicals
trade partners	:	Norway, U.K., West Germany, Denmark, Finland	West Germany, U.K., Denmark, U.S., Finland, Norway

GNP (1975)	:	$66,830,000,000
GNP/capita (1975)	:	$8,150

Formerly the bulk of the production of Sweden's shipbuilding industry was for export but the larger part is today for Swedish shipowners. Swedish yards have the facilities to build vessels of up to 700,000 tons.

Swedish-flag vessels carried 20 percent of Sweden's ocean-borne foreign trade in 1977 (15 percent of imports and 30 percent of exports).

GOVERNMENT AIDS

Operating Subsidy or Aid

There is no operating subsidy for ships in the foreign trade.

In the domestic trade, aid is granted in the national interest to some minor companies serving the archipelago of Stockholm, Gothenburg, etc. and a company serving the Isle of Gotland.

Construction Subsidy or Aid

There is no direct construction subsidy for vessels operating in the foreign trade.

Ship Export Credits

As for other industries, export credit insurance for ships may be obtained from the Swedish Export Credits Guarantee Board. Premium rates vary according to the risks covered, the length of the credit, the buyer's country, etc.

Tax Benefits

The only advantage shipping has over other industries is the permission to transfer taxable earnings from the sale of vessels to a special fund, which, if used to acquire new vessels, is not taxable. All industries including shipping, are entitled to transfer profits to a tax-free fund for the equalization of market fluctuations in the business cycle.

Ships over 20 tons (whether Swedish-built or imported) are exempt from value added tax. A rebate of value added tax is paid in the case of ships exported, under the rules for export industries in general.

Custom Duties

Imported materials for building ocean-going ships (whether built for export or national owners) are exempt from customs duty.

Loans and Interest on Loans

The government provides guarantees, within certain limits, for loans obtained by Swedish shipyards from domestic or foreign credit institutions. The aim of these guarantees is to help shipyards to refinance part of their outstanding construction credits to Swedish and foreign shipowners. They are used primarily as collateral security for loans secured by mortgage.

This system, in effect since 1963, was continued under the Shipbuilding Bill of November 2, 1978, (not yet decided by the Swedish Parliament). According to the propositions of the Bill the actual volume of the guarantees will be allowed to increase with $1.1 billion to the extent of $3.8 billion before the end of 1981.

Swedish owners, ordering from Swedish yards, are proposed in the above mentioned Bill to receive a "write-off-loan" of a maximum of 25% of the newbuilding price. The loan runs for 5 years and is free of interest. After 5 years the ship will be assessed and if the value of the ship has increased the gain will be divided equally between the state and the owner. Credit guarantees of a maximum of 70% of the building price can also be obtained. The loans covered by the guarantees may have a maturity period of a maximum of 12 years. To receive a "write-off-loan" and/or credit guarantees the order must be placed with a Swedish yard before the end of 1979. The ship to be delivered before the end of 1980.

The Swedish Ships' Mortgage Bank is granting credits to Swedish shipowners against a mortgage within 50% and 70% of the estimated value of a new ship. The credit period is 15 years for loans with 50% of the value and 10 years between 50 and 70% of the value. The loans are to be redeemed by annual installments of one-fifteenth per annum and one-tenth per annum respectively. The rate of interest is dependent on the current rate of interest ruling on the bond market, but remains unchanged during the credit period. Outstanding loans amounted to about $250 million on December 31, 1977.

To meet temporary economic difficulties the Bank has been given facilities to postpone the annual installment provided that the risk situation is acceptable.

Since July 1, 1977, the Government can issue guarantees for loans to Swedish shipowners. The aim of this guarantee system is to prevent modern Swedish ships being sold at extremely low prices. The ships must belong to shipping companies with a clear ability to overcome their economic problems and in the future remain as profitable companies. The total volume of these guarantees for Swedish owners will amount to a maximum of $115 million.

In a Bill to the Parliament of November 2, 1978, (not yet decided by the Swedish Parliament) the two major shipping companies of Sweden, the Salen Shipping Group and The Brostrom Shipping Group, are proposed to receive specially designed support by government guarantees and loans for the period 1979-1982 for The Salen Shipping Group respectively, 1979-1983 for The Brostrom Shipping Group. The Brostrom Shipping Group is also poposed to receive a direct financial contribution of $18 million.

Depreciation

All industries are permitted to depreciate at 30% of book value per year or to a complete writeoff in 5 years. Depreciation may not exceed the purchase price of the vessel.

On a contracted vessel to be delivered in the period 1966-1980 depreciation not exceeding 30% of the contracted price is permitted prior to delivery.

Government Ownership

The government has nationalized all the major shipyards, except Kockums, placing them under a holding company called Swedyards Corporation.

Other

In early 1977, Swedish shipowners received permission to register older, less sophisticated vessels under third-flags provided a special allowance is granted and a new Swedish vessel is taken into service.

SWITZERLAND

ECONOMIC BACKGROUND

Size of Fleet: 26 vessels of 364,000 dwt. tons.

Tankers :	8% of vessels;	2% of tonnage
Bulk Carriers:	19% of vessels;	47% of tonnage
Freighters :	73% of vessels;	51% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$14,841	$14,772
commodities :	machinery and equipment, chemicals, precision instruments, metal products, textiles, food stuffs	machinery and transportation equipment, metals and metal products, food stuffs, chemicals, textile fibers and yarns
trade partners :	West Germany, France, Italy, U.S.	West Germany, France, Italy, U.S., U.K.

GNP (1975) : $53,840,000,000
GNP/capita (1975) : $8,410

The Government of Switzerland maintains tight control over registration of oceangoing vessels under the Swiss flag. Corporations owning ships under Swiss registry must be listed in the Swiss Commercial Register, must have its operating headquarters and its center of activity in Switzerland, and all of its managers, associates, or partners (as well as shareholders in the case of a publicly-held corporation) must be Swiss citizens resident in Switzerland.

The Swiss government permits up to 50 percent of the financing of Swiss-flag sea-going vessels to be foreign financing as long as the above requirements are met.

There are no statistics available as to the percentage of Switzerland's foreign trade which is carried by Swiss-flag vessels. In peacetime ships are trading in free competition and most of the goods carried are for foreign account. Swiss-flag vessels carried 0.08 percent of U.S. oceanborne foreign trade in 1970 (0.03 percent of U.S. imports and 0.15 percent of U.S. exports).

GOVERNMENT AIDS

The Swiss Government gives no financial aid at the present time to its shipping and shipbuilding industries.

THAILAND

ECONOMIC BACKGROUND

Size of Fleet: 29 vessels of 245,000 dwt. tons.

Tankers :	38% of vessels; 62% of tonnage
Bulk Carriers:	3% of vessels; 1% of tonnage
Freighters :	57% of vessels; 37% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$2,949.9	$3,636.3
commodities :	rice, sugar, corn, rubber, tin, tapioca	machinery and transport equipment, fuels and lubricants, base metals, chemicals, and fertilizers
trade partners :	Japan, Netherlands, U.S., Singapore	Japan, U.S., Saudi Arabia, West Germany
GNP (1975) :	$14,600,000,000	
GNP/capita (1975) :	$350	

During 1972, Thai-flag vessels carried 4.5 percent of Thailand's oceanborne foreign trade (2.86 percent of imports and 7.23 percent of exports).

Bangkok is Thailand's major port.

GOVERNMENT AIDS

Cargo Preference

The transport of state financed goods must be carried out by national flag vessels.

Government Ownership

The government owns the following companies:

Thai Maritime Navigation Co., Ltd.
Thai Navigation Co., Ltd.

TURKEY

ECONOMIC BACKGROUND

Size of Fleet: 126 vessels of 1,556,000 dwt. tons.

Tankers :	22% of vessels; 38% of tonnage
Bulk Carriers :	10% of vessels; 28% of tonnage
Freighters :	56% of vessels; 32% of tonnage
Combination Carriers:	12% of vessels; 2% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$1,960.2	$5,129.9
commodities :	cotton, tobacco, hazelnuts, citrus fruit	machinery, chemic transport equipme fertilizers
trade partners :	West Germany, U.S., Switzerland, Italy	West Germany, U.S U.K., Italy, Fran
GNP (1975) :	$36,030,000,000	
GNP/capita (1975) :	$900	

The Turkish merchant fleet is composed primarily of relatively small freighters engaged in Turkey's coastal trade, but fleet modernization took place under the impetus of the Second Five-Year Development Plan, which ended in 1972.

The Turkish Government is building a new modern shipyard at Pendik near Istanbul, but the Pendik yard will not be operational until sometime in the Third Plan period. Only two Turkish shipyards, both government-owned, can currently build large oceangoing vessels. These are the Camialti Shipyard and Golcuk Naval Shipyard.

Turkey's major ports are Istanbul and Izmir. During 1970, Turkish-flag vessels carried 28% of Turkey's oceanborne foreign trade (37 percent of imports and 19 percent of exports).

GOVERNMENT AIDS

Loans

In an effort to improve the condition of the fleet, the government established in 1967 a $4 million fund at the Maritime Bank to be used for the construction of steel ships (under 6,000 dwt. tons) during 1968. The loans were made with six years repayment period and six percent interest.

Cargo Preference

All "public sector" cargoes must be carried in Turkish flag ships. Furthermore, the Maritime Bank exerts pressure on Turkish exporters and importers to ship commercial cargoes on Turkish ships when available.

UNITED ARAB EMIRATES

ECONOMIC BACKGROUND

Size of Fleet: 11 vessels of 226,000 dwt. tons.

Tankers :	9% of vessels; 60% of tonnage
Bulk Carriers:	0% of vessels; 0% of tonnage
Freighters :	91% of vessels; 40% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$8,507.3	$3,419.7
commodities :	petroleum, pearls, fish	food, consumer and capital goods
trade partners :	Japan, France, U.S., E.C., India	Japan, U.K., U.S., E.C., India

GNP (1975) :	$8,880,000,000
GNP/capita (1975) :	$13,600

GOVERNMENT AIDS

Government Ownership

The Abu Dhabi National Tanker Company is a wholly owned subsidiary of the state-controlled Abu Dhabi National Oil Company.

The government of Dubai owns 30 percent of the equity in the Dubai Maritime Transport Company.

UNITED KINGDOM

ECONOMIC BACKGROUND

Size of Fleet: 1,508 vessels of 54,934,000 dwt. tons.

Tankers	:	28% of vessels; 60% of tonnage
Bulk Carriers	:	23% of vessels; 27% of tonnage
Freighters	:	47% of vessels; 13% of tonnage
Combination Carriers	:	2% of vessels; 0% of tonnage

Foreign Trade: (1976)

		exports	imports
value (million US$)	:	$46,264	$55,974
commodities	:	machinery, transport equipment, metal products, chemicals, textiles	non-ferrous metals, petroleum, textiles, chemicals, food stuffs
trade partners	:	U.S., West Germany, Netherlands, Brazil	U.S., West Germany, Netherlands, France

GNP (1975)	:	$211,700,000,000
GNP/capita (1975)	:	$3,780

The United Kingdom has been a maritime nation throughout its history and, as an island nation, has had a heavy dependance on foreign trade. The British fleet is one of the most modern and diversified in the world, and is a substantial and consistent contributor to the balance of payments.

The United Kingdom has at least 300 ports, of which 90 ports handle foreign trade. British ports handle about 367,000,000 gross tons of cargo annually, but about one third of this tonnage is in the coastal trade.

In 1975 United Kingdom registered vessels carried 34 percent of the United Kingdom's oceanborne foreign trade cargo (32 percent of imports and 45 percent of exports).

GOVERNMENT AID

All new aid schemes for the shipbuilding industry must be approved by the European Community Council. The requirements Brussels places on aid schemes are 1) they are not to operate against other European Community yards; and 2) that aid goes only to yards that stand a long term chance of survival.

Operating Subsidy or Aid

There is no operating subsidy in the foreign trade.

In the domestic trade, grants are given to provide transportation (1) to the western highlands and islands of Scotland, (2) for service between the north and south isles and the mainland of Orkney, and (3) for service between the north isles and the mainland of Shetland. The purpose is to provide essential transport service to the above remote and sparsely populated areas. The authority for this subsidy is the Highlands and Islands Shipping Service Act, 1960. The cost of this is about $2,000,000 a year. Local authorities in the Highlands and Islands are making increased use of the powers to assist rural ferry services (including some important services to the islands) given by Section 34 of the Transport Act 1968 which also empowers the government to make grants towards this expenditure.

Construction Subsidy

An intervention fund with starting capital of $111.8 million was established in 1977 to help British shipbuilding compete against foreign yards.

Credit Facilities for Export Orders

No special facilities exist for financing the export of ships. But under arrangements worked out with the banks, in cases where an unconditional bank or financial guarantee is obtained from the Export Credits Guarantee Department, finance for export is available as follows: Where the credit is on terms of up to two years, finance is available at a rate calculated at .5 percent above the published bank base rate. Where the credit is on terms of two years or more, finance is available at a fixed rate of interest which at present is 7½ percent for ships, though, to this figure has to be added both the credit insurance premium and the customary bank charges, giving a minimum interest rate of 8 percent.

Taxation

Relief is given in respect of certain indirect taxes borne by the shipbuilding industry and industries supplying it. The rate of relief is 2 percent of the value of ships delivered by the builder under contract, and represents the average incidence of these indirect taxes on shipbuilding costs.

Ships of 15 gross tons or more are exempt from Value Added Tax.

Exemption From or Rebates of Customs Duty

Goods imported for use on ships are exempted from duty under shipwork end-use relief.

The relief applies to imports from any source for use in vessels designed as seagoing, and, with the exception of lifeboats and fishing boats, having an overall length of not less than 12 metres.

Credits and Loans

Clearing banks make loans available to shipowners at a fixed rate of interest and the loans are guaranteed by the Government. The terms of the scheme conform to the OECD Understanding on Export Credit for Ships.

The Industry Act 1972 as amended by the Industry Act 1975 provides for Government guaranteed credit to finance the construction of ships and mobile offshore installations in the United Kingdom for U.K. shipowners. The purpose of the scheme is to ensure that credit terms available under other countries' export credit schemes do not place U.K. shipyards at a disadvantage when competing for orders from U.K. shipowners.

Cost Escalation Insurance

The U.K. Government operates a temporary scheme of cost escalation insurance on sales by U.K. shipbuilders to both the home and export market. The scheme is designed to give shipbuilders a measure of protection against exceptional and unpredictable increases in U.K. costs. To qualify for cover a prospective contract must be for the supply of items with an individual unit value of about $1,000,000; have a manufacturing period of at least 2 years; and have a basic contract price of at least $4,000,000.

Government Ownership or Shareholding

On July 1, 1977, nineteen shipbuilding companies, five diesel marine engine manufacturers and three training companies were nationalized to form the British Shipbuilders Corporation (BSC). Labor, industry and government are represented in a management which plans to use economies of scale to obtain more orders for the industry. The shipyards will remain decentralized so that individual shipyard performance can be measured. The pooling of orders will take place only when required to facilitate the securing of an order.

The government has the following shipping interests:

A. An interest in British Petroleum, the parent company of BP Tankers.

B. An interest, similar to that in other nationalized bodies, in the Railways Board, the Central Electricity Generating Board, and the National Freight Corporation, which own ships directly and indirectly.

C. British Shipbuilders Corporation is totally owned by the government.

Research Grants

Research related to shipbuilding is done by the state-run National Physical Laboratory. The government also supports selected R and D work done by firms or research associations, and gives specific aid to certain projects of the British Ship Research Association. State aid for R and D work averages about $4 million per annum.

UNITED STATES

ECONOMIC BACKGROUND

Size of Fleet: 842 vessels of 18,566,000 dwt. tons.

Tankers :	32% of vessels;	58% of tonnage
Bulk Carriers :	2% of vessels;	3% of tonnage
Freighters :	59% of vessels;	37% of tonnage
Combination Carriers:	7% of vessels;	2% of tonnage

Foreign Trade: (1975)

	exports	imports
value (million US$):	$115,006	$129,567
commodities :	machinery, chemicals, autos, grain, iron and steel products, textiles, petroleum products	petroleum, coffee, sugar, iron and steel products, newsprint, copper
trade partners :	Canada, S. America, W. Europe, Japan, Asia	Canada, S. America, Middle East, W. Europe, Japan, Asia

GNP (1975) :	$1,519,890,000,000
GNP/capita (1975) :	$7,120

At the end of FY 1977, there were 60 vessels of 5.6 million dwt. tons on order or under construction for U.S. registry. All except two are to be constructed in U.S ship-yards.

U.S.-flag ships carried 4.5 percent of the country's oceanborne foreign trade in 1977 (3.9 percent of imports and 5.9 percent of exports).1/

1/ Preliminary data

Operating Subsidy

Operating-differential subsidy is granted to United States ship operators to place U.S.-flag vessels operating costs on a parity with those of foreign competitors. Subsidy is based on the difference between the fair and reasonable cost of insurance, (protection and indemnity and hull and machinery premiums), maintenance, repairs not compensated by insurance, wages of officers and crews, and subsistence of officers and crews on passenger vessels, and the estimated costs of the same items if the vessels were operated under foreign registry.

Subsidy is paid pursuant to operating subsidy contracts between the government and the operators. Authority for the payment of subsidy under these contracts is contained in Title VI of the Merchant Marine Act, 1936, as amended. In accordance with government/industry efforts to reduce government expenditures on privately owned merchant shipping, recently executed operating subsidy contracts have not included subsidy for hull and machinery insurance premiums*, and maintenance and repair costs, pursuant to the provisions of section 603 of the Act which permit the parties to the operating subsidy contracts to agree to a lesser amount of subsidy than that which is necessary to achieve parity.

Under Title VI, the operators holding subsidy contracts must be United States citizens and must possess certain other qualifications, the Secretary of Commerce must determine that the subsidized vessels are of United States construction and that the operation of such vessels in an essential service is required to meet foreign-flag competition and to promote the foreign commerce of the United States. Under certain circumstances, as to passenger vessels, in addition to the liner trades, operating subsidy is also authorized for the cruiser trades. In respect to cargo vessels, prior to the enactment of the Merchant Marine Act of 1970 which extensively amended the 1936 Act, operating subsidy was payable only to liner type vessels with scheduled sailings on established trade routes. The 1970 amendments broadened the scope of the term essential service to authorize the payment of operating subsidy to aid in the operation of bulk carrier type vessels, whether or not operating on particular services, routes, or lines. Also, Public Law 91-603 enacted December 31, 1970, which further amended Title VI of the 1936 Act, permits the payment of operating subsidy on leased as well as owned vessels.

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*In some instances, protection and indemnity insurance premiums and deductibles are not included.

The subsidized operators under the operating-differential subsidy contracts must assume the obligations of a replacement program under which they are contractually required to construct new vessels to replace the existing vessels in their subsidized fleets as the existing vessels become obsolete. The number of vessels to be built under the replacement program and the vessels' designs are agreed upon after negotiations between the subsidized ship operators and the United States.

Since the enactment of Public Law 91-603, permitting the payment of operating subsidy on leased vessels, many of the ship operators, in order to raise the large amounts of capital necessary for the construction of modern vessels have taken advantage of the leveraged lease financing method to cover the shipbuilding costs. Under this arrangement the ownership of the newly constructed vessels is vested in financial institutions and the vessels are leased by these institutions to the subsidized operators under bareboat charters. This method of financing, however, is not used solely in connection with the construction of vessels by operators who are receiving operating subsidy.

The total amount of subsidy paid under the operating-differential subsidy contracts during fiscal year 1977 was $344 million. Subsidy paid during fiscal year 1977 under special operating-differential subsidy contracts executed in connection with the shipment of grain to the Soviet Union was $34.3 million.

Construction Subsidy

Under the provisions of Title V of the Merchant Marine Act, 1936, as amended, provision is made for a construction-differential subsidy to build vessels to be used in the foreign commerce of the United States. The purpose of the subsidy is to enable United States shipyards to construct vessels in the United States on a parity with their foreign competitors, and thus enable U.S. ship purchasers to obtain U.S.-built vessels at competitive world prices.

The Merchant Marine Act, 1936, was further amended by Public Law enacted July 31, 1976, which provides that, for construction contracts which are executed on a negotiated basis, as well as for those executed on a bid basis, the vessels being constructed under Title V may be aided by construction subsidy up to a rate of 50 percent of the domestic cost of the vessel.

A shipyard of the United States or Puerto Rico or a proposed purchaser who meet the qualifications set forth in the Merchant Marine Act, 1936, as amended, may apply for construction subsidy to aid in the construction or reconstruction of a vessel which will meet the requirements of the foreign commerce of the United States and will aid in the promotion and development of such commerce, and which will be suitable for use for military purposes in time of national emergency. Regardless of whether the shipyard or purchaser is the applicant, the construction subsidy is paid to the shipyard. Vessels built with the aid of construction subsidy must be manned by U.S. citizen crews, and must remain documented under the laws of the United States for not less than 25 years, except with respect to tankers and other liquid bulk carriers which must remain so documented for not less than 20 years.

The amount of construction subsidy awarded in fiscal year 1977 was estimated at $159.8 million.

There is no construction subsidy for vessels operating in the domestic trade.

Tax Benefits

In general, shipping is treated similarly to other industries, except that United States citizens owning or leasing eligible vessels may obtain certain tax benefits through the maintenance of Capital Construction Funds and Construction Reserve Funds to construct qualified vessels.

The Capital Construction Fund (CCF) program is a method of aiding United States vessel operators in accumulating capital necessary for the construction, reconstruction, and acquisition of vessels of United States registry built in the United States. The purpose of the program is to remove certain competitive disadvantages that U.S. operators have relative to foreign-flag operators. The CCF extends tax deferral privileges to vessel operators in the U.S. foreign commerce and in the non-contiguous and Great Lakes domestic trades.

The CCF program is authorized by section 607 of the Merchant Marine Act, 1936, as amended, and arose from the 1970 amendments to the Act. Prior to 1970 only subsidized operators had tax deferred funds, referred to as Capital Reserve Funds, under section 607. The revised CCF program under section 607 is available to both subsidized and nonsubsidized operators, and the old Capital Reserve Funds have been phased out of existence.

Section 607 allows for the deferment of income taxes on certain deposits of money or other property, if the funds are used to construct vessels in U.S. shipyards. An operator may deposit earnings or gains realized from the operation of an agreement vessel; net proceeds realized from the sale or other disposition of an agreement vessel or from insurance or indemnification from the loss of an agreement vessel; and earnings from the investment or reinvestment of amounts on deposit in the fund. In general, the taxable income of the operator is reduced to the extent deposits of money are made into the fund under these ceilings.

An operator may also deposit in a CCF amounts allowable as a depreciation deduction with respect to agreement vessels. Such deposits do not directly reduce taxable income, but the earnings from such funds may be accumulated on a tax deferred basis.

By the investment of the assets in the CCF, a fundholder may compound the fund benefits and develop an expanded pool of tax deferred funds. However, the investment of the fund in securities and stocks is subject to certain restrictions which are intended to preserve the integrity of the fund.

A fund established pursuant to section 607 is maintained in three accounts: an ordinary income account, a capital gain account, and a capital account. The manner in which the funds would be taxed if not deposited is the primary determinant of the account to which a deposit is credited. When qualified withdrawals are made from the fund for the construction, reconstruction or acquistition of vessels, barges or containers, certain basis adjustments are made to the assets being acquired depending upon the account from which the monies are withdrawn. Withdrawals from the ordinary income account reduce the tax basis of the acquired vessel by an amount equivalent to the amount withdrawn. Withdrawals from the capital gain account result in a partial reduction of basis, and withdrawals from the capital account do not reduce the basis of the vessel.

If a withdrawal is made from the fund for other than a qualified purpose, any amounts withdrawn from the ordinary income and capital gains accounts are taxable as if earned in the year of withdrawal. Additionally, the tax attributable to the nonqualified withdrawal is subject to an interest charge for the period between the year the amount was deposited and the year the withdrawal is made. Since the tax is paid on nonqualified withdrawals, no adjustments to basis arise as a result of a nonqualified withdrawal.

The Construction Reserve Fund (CRF) authorized by section 511 of the Merchant Marine Act, 1936, as amended, is also a financial assistance program which provides tax deferral benefits to United States shipowners. Through the CRF shipowners operating vessels in the foreign or domestic commerce of the United States can defer the gain attributable to the sale or loss of a vessel. The proceeds deposited must be used to construct, reconstruct, or acquire vessels of United States registry built in the United States. Although any gains on such transactions are not recognized for income tax purposes if the deposits are properly expended for a vessel, the basis for determining depreciation of such a vessel is reduced by the amount of any such gains.

The ability to defer gain on certain transactions through deposits to the CRF applies only to vessel owners. Citizens operating a vessel owned by another party cannot benefit from the provisions relating to the non-recognition of gain from the sale or loss of a vessel.

Section 511 also permits a vessel owner or operator to deposit into the CRF earnings from the operation of United States registry vessels and earnings from the investment of the fund. Such deposits do not exempt the taxpayer from tax liability on the earnings nor do they postpone the time such earnings are includable in gross income. However, earnings so deposited are considered to have been accumulated for the reasonable needs of business and are not subject to accumulated earnings tax. This ability to accumulate funds for the construction, reconstruction, or acquisition of a vessel is the only benefit available through the CRF to a non-owner operator of a vessel.

Loans and Interest on Loans

Pursuant to Title XI of the Act, the Maritime Administration is authorized to guarantee obligations (including notes, bonds and bank loans) to aid in financing the construction or reconstruction of vessels designed principally for research, or for use in the domestic or foreign commerce of the United States. The shipowner, managing agent, and bareboat charterer are required to be U.S. citizens. In the opinion of the United States, the shipowner and/or bareboat charterer must possess the qualifications necessary for the adequate operation of the mortgaged property and the proposed project must be economically sound.

Obligations during the construction period can be issued on a short or long term basis with the short term obligations usually converted to long term obligations upon maturity. At delivery, a mortgage is then placed on the vessel in favor of the Secretary if guarantees were issued during the construction period. If there is no guarantee during the construction period, a mortgage is placed on the vessel at the time the guaranteed obligations are issued. In certain instances a guarantee may be placed on an existing vessel to pay for the construction cost of a new vessel.

Vessels eligible for guarantees under Title XI, of design satisfactory to the United States, include passenger, cargo and fishing vessels, tankers, towboats, dredges, barges, floating drydocks, oceanographic research or instruction or pollution treatment, abatement or control vessels.

Guarantees on the obligations are granted up to 75 percent or to 87½ percent of the shipowner's cost, depending on the type of vessel being constructed or reconstructed. Ships being built with the aid of construction subsidy may also be eligible for a Title XI guarantee up to 75 percent of the construction cost of the vessel to the shipowner.

Public Law 90-341 authorizes interest at rates not to exceed such percent annually on the principal obligations outstanding as the Secretary of Commerce determines to be reasonable taking into account private market conditions and the risks of the government.

The purpose of Title XI is to foster private rather than direct government financing of vessel construction and reconstruction.

As of September 30, 1977, Title XI guarantees in force amounted to nearly $5.8 billion.

<u>Other</u>

Section 510 of the Act authorizes the Maritime Administration to acquire privately-owned obsolete vessels in exchange for an allowance of credit payable to the shipowner or shipbuilder on the construction of new vessels and also to acquire mariner class vessels constructed under Title VII of the Merchant Marine Act, 1936, and Public Law 911, Eighty-first Congress, and other suitable vessels, constructed in the U.S., which have never been under foreign documentation, in exchange for obsolete vessels in the National Defense Reserve Fleet.

Under sections 501 and 509 national defense features which are paid for entirely by the government are included in vessels under construction. If a vessel is built with construction subsidy, such payments are not considered part of the subsidy. Some of these national defense features are:

1. Increased shaft horsepower, using naval design criteria.

2. Atomic, biological, and chemical washdown facilities.

3. Increased turbogenerator capacity.

4. Heavy lift boom structure suitable for future installation of a 60 ton boom.

5. Increased boom lift capacity, from 5 to 10 tons at certain hatches.

6. Limited fueling-at-sea installations.

Certain types of government-owned or financed cargoes are preferentially routed via U.S.-flag commercial vessels.1/ In some of the government-aid programs the sponsoring agency assumes the additional cost of U.S.-flag freight over those for foreign flags. For example, under Title I of Public Law 480, the Department of Agriculture finances, with dollars, the ocean freight differential for U.S.-flag vessels required to be used. The foreign governments finance in U.S. dollars that portion of the ocean freight equal to the world market rate.

1/ The various statutes under which these cargoes move are:

1. The 1904 Act which gives U.S.-flag ships preference in the transportation of supplies for the armed services in direct overseas support of the U.S. military establishment.

2. Public Law 664, enacted in 1954, which is included in the revised 1936 Act. This Act stipulates that at least 50 percent of all cargo must be carried on U.S.-flag ships to the extent of their availability at fair and reasonable rates.

3. Public Resolution No. 17, enacted in 1934 applies to Ex-Im Bank loans for the exportation of goods from the United States and provides for their carriage exclusively in U.S.-flag ships except when waivers are granted by the Maritime Administration, as provided in the Resolution.

Section 714 of the Act provides that if the Secretary of Commerce shall find that any essential trade route cannot be otherwise successfully developed and maintained, he may have ships built to be chartered to American-flag operators at not less than four percent per annum of the estimated foreign cost of such ships, plus an annual percentage of the depreciated foreign cost on the basis of a 25 year life, as determined by the Secretary of the Treasury and plus an allowance for administrative costs. Such charters may contain an option to purchase such ships within five years from date of delivery under the charter at the estimated depreciated foreign cost. There are no moneys appropriated to build ships for this purpose.

Further chartering authority is found in section 510(d) of the Act which permits the owner of an obsolete vessel which has been traded in on new construction to use the obsolete vessel during the construction period at a rate to be fixed by the Assistant Secretary of Commerce for Maritime Affairs.

Coastwise and intercoastal trade is restricted to U.S.-flag ships.

The U.S./U.S.S.R. maritime agreement provides that each country shall carry a "substantial share", (not less than one-third) of the total number of weight tons of bilateral cargo carried in the trade between them.

An agreement between the U.S. and Brazil gives the national-flag carriers of each country equal access to the government controlled cargoes traded between them.

URUGUAY

ECONOMIC BACKGROUND

Size of Fleet: 18 vessels of 250,000 dwt. tons.

Tankers	39% of vessels;	72% of tonnage
Bulk Carriers	0% of vessels;	0% of tonnage
Freighters	55% of vessels;	24% of tonnage
Combination Carriers	6% of vessels;	4% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$)	$520.74	$617.37
commodities	wool, meat, hides, linseed oil	petroleum products, machinery, transport equipment, foodstuffs
trade partners	West Germany, U.S., Brazil	Brazil, Kuwait, Iraq, Argentina, U.S.
GNP (1975)	$3,600,000,000	
GNP/capita (1975)	$1,300	

Uruguayan-flag vessels carried 15 percent of the country's oceanborne foreign trade in 1975 (20 percent of imports and 6 percent of exports).

Montevideo is Uruguay's principal port.

GOVERNMENT AIDS

The government policy is to facilitate merchant marine operations, but it grants no direct subsidy.

Tax Benefits

The government-owned shipping lines are exempt from some taxes. There is a proposal under consideration for the exemption from all taxes, but is has not as yet been approved.

Uruguayan-flag carriers are eligible for certain tax benefits provided: (1) the route and service is approved by the National Transportation Directorate; (2) the majority of the partners of the shipping firm are Uruguayan citizens resident in the country; (3) the majority of the shares of the firm are held by native borne or legal Uruguayan citizens; and, (4) the firm has fulfilled its other tax obligations. The beneifts are: (1) exemption from import duties on ships, equipment, spare parts, fuels and lubricants; (2) sales, property, construction and repair, and registration taxes, consulor fees, and value added tax on import or export freight cost; (3) free use of foreign exchange generated in normal shipping operations; and, (4) favorable credit terms.

Importers and exporters receive a tax rebate if they ship their goods on Uruguayan-flag vessels.

Loans

Firms whose majority of stockholders (and/or members of their Board of Directors) are Uruguayan are eligible for loans from the Merchant Navy Development Fund. These loans can be for a) the construction of ships and necessary major repair work b) the renewal, conversion and modernization of ships, or c) the purchase of "new" ships built not more than 15 years before the date of the loan application.

Cargo Preferences

Uruguayan-flag oceangoing vessels, except those engaged in trade with LAFTA countries, pay consular, pilotage and wharfage fees and sanitation taxes, as do foreign-flag oceangoing vessels. However, there is a 25 percent reduction in wharfage and dockage fees, and an exemption from the daily fees charged non-working vessels for Uruguaryan-flag ships. Trade with LAFTA countries is considered, by the government, to be coastal trade and cargoes from those countries, if arriving on Uruguayan-flag vessels, are exempt from payment of consular fees of 12 percent. Uruguayan vessels are exempt from the payment of small lighthouse fees. Foreign as well as Uruguayan-flag vessels contribute 15 percent of ships' wages to the Government Stevedores' Labor Association.

The government corporation, ANCAP, has a monopoly on refining crude oil. ANCAP uses national as well as chartered foreign-flag vessels in the carriage of imports with 31 percent participation for national vessels and 69 percent for foreign-flag vessels. Local subsidiaries of Exxon, Texaco, and Shell also import crude oil. They pay ANCAP a refining fee, and then market the refined product.

Merchandise arriving in Uruguay for use by state entities as well as certain exports are entitled to "fiscal exemptions." Such cargo must, however, be shipped via Uruguayan-flag vessels.

Law No. 14.650 establishes as a general policy the reservation of 50 percent of Uruguayan waterborne foreign trade and in particular 100 percent of imports for Uruguayan-flag vessels. Foreign ships can be used if no Uruguayan-flag vessels are available and prior authorization has been obtained from the Minister of Transport and Public Works. Such vessels must be included in international maritime transport exchange agreements between Uruguay and the flag country.

The government of Uruguay is empowered under the law to extend the ship Uruguayan requirement to exports that are tax exempt or are financed by the national banking system.

Uruguay has agreements with Brazil and Argentina which provide for an equal sharing of the cargo carried between them.

Government Ownership

The government owns and operates, through the National Port Administration, two small river boats; through the National Fuels, Alcohol and Portland Cement Administration (ANCAP), two oceangoing and one coastal vessel, and through the Ministry of Defense, two large tankers chartered to ANCAP for the transport of crude to the refinery in Montevideo.

VENEZUELA

ECONOMIC BACKGROUND

Size of Fleet: 44 vessels of 616,000 dwt. tons.

Tankers	: 34% of vessels;	66% of tonnage
Bulk Carriers	: 7% of vessels;	3% of tonnage
Freighters	: 57% of vessels;	30% of tonnage
Combination Carriers	: 2% of vessels;	1% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$8,662	$6,100
commodities :	petroleum (91% of exports), iron ore, coffee, fish, metal products	transport equipment, iron and steel, wheat, machinery, chemicals
trade partners :	U.S., Netherlands, Antilles, Canada	U.S., Japan, West Germany
GNP (1975) :	$27,320,000,000	
GNP/capita (1975) :	$2,280	

Venezuela is heavily dependent on the export of petroleum and has a natural interest in maintaining a merchant fleet to facilitate exports. Average daily production of petroleum is about 3,700,000 barrels.

Venezuelan-flag vessels carry about 10 percent of Venezuela's oceanborne foreign trade (10 percent of imports and exports).

Operating Subsidy or Aid

In theory the government makes up the deficits of the Compania Anonima Venezolana de Navegacion (CAVN) in order to keep the company in operation. However, the majority of the operating balances since 1955 has been favorable.

Cargo Preference and Cabotage

The Law for the Protection and Development of the National Merchant Marine stipulates that ships should be 75 percent owned by nationals to qualify as Venezuelan-flag, and on the general cargo side the law requires 50 percent of the traffic of each shipper and importer to travel in Venezuelan-flag vessels; it also further excludes the Venezuelan private sector from much of this trade.

In 1966, the United States and Venezuela developed an arrangement whereby each party would make up to 50 percent of the cargo subject to Venezuelan Decree 331 and US PR 17 available to vessels flying the flag of the other country.

Federal, state or municipal government executed or financed cargoes are reserved 100% for Veneuzuelan government owned ships, or in case of non-availablity, for other Venezuelan vessels. Foreign-flag vessels may participate in the cargo reserve on the basis of reciprocity.

The Pilotage Law of 6 August 1971, allows the national executive to grant Venezuelan ships exoneration of up to 50 percent of the charges established by the law. Chapter VI, Section 1, Article 24 of the general regulations of the law states that national-flag ships pay 50 percent of the charges established by the individual pilotage regulations of the different national ports.

CAVN maintains joint services with several "associated"1/ foreign-flag lines and under the agreements establishing the joint services imports partially or totally exempt from import duties (known as "exonerated cargo"),2/ must move on CAVN or "associated" line ships. The "exoneration" is at the discretion of the government agencies concerned and amounts to about 15 percent of the value of Venezuelan imports. This assures a definite share of the cargo to CAVN in areas where it maintains a service.

1/ CAVN is associated with a number of lines in the Scandinavian countries, Europe and Japan whereby joint services are maintained.

2/ Government financed cargoes. The Government of Venezuela points out the majority of "exonerated cargo" is bulk cargo that is not normally carried by CAVN ships.

There is one United States company which has such a pooling agreement with CAVN under which it participates in the carriage of "exonerated cargo" on U.S. registered vessels.

Coastal trade is restricted to Venezuelan vessels.

The National Executive shall reserve for Venezuelan-flag ships the transport of a percentage that is not less than 10 percent of the export and import of petroleum and its derivatives, which shall augment gradually until 50 percent of the total is reached. In a like fashion, the transport of iron ore, wheat and other free-flowing cargo shall be treated equally whether they are exports or imports.

Government Ownership

CAVN is a stock company owned by the government.

Diques y Astilleros Nacionales Compania Anonima (DIANCA), the national shipyard company at Puerto Cabello, is fully financed by the government.

The government holds a 55 percent interest in Astinave (the Venezuelan shipyard company located at Los Taques) with the remainder owned by the Spanish-government through the state-owned Spanish Shipyards Company.

ZAIRE

ECONOMIC BACKGROUND

Size of Fleet: 11 vessels of 152,000 dwt. tons.

Tankers :	0% of vessels; 0% of tonnage
Bulk Carriers :	0% of vessels; 0% of tonnage
Freighters :	82% of vessels; 84% of tonnage
Combination Carriers:	18% of vessels; 16% of tonnage

Foreign Trade: (1976)

	exports	imports
value (million US$):	$1,262.7	$922.2
commodities :	copper, cobalt diamonds, coffee	consumer goods, foodstuffs, mining and other machinery, transportation equipment and fuels
trade partners :	Belgium, U.S., Italy, France	Belgium, France, U.S., West Germany
GNP (1975) :	$3,450,000,000	
GNP/capita (1975) :	$140	

Zaire has two major ports, Matadi and Boma.

Cargo Preference

Law 74-014 (7-10-74) gives Compagnie Maritime Zairoise (CMZ) the monopoly of sea transport of exports from the Republic of Zaire and the monopoly on all products imported with the assistance of the Bank of Zaire.

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